

*Manual for*

# **QUALITY CONTROL**

*for Plants and Production of*

# **STRUCTURAL PRECAST**

# **CONCRETE PRODUCTS**

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**FOURTH EDITION**

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**MNL-116-99**



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Every effort has been made to ensure the accuracy of the information presented in this Manual. However, PCI cannot accept responsibility for errors, oversights, or the misuse of the information contained herein. The user must recognize that no manual or regulation can substitute for experience and sound judgment. This publication is intended for use by personnel competent to evaluate the significance and limitations of the information it contains, and accept responsibility for its proper interpretation and application.

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# FOREWORD

This is the fourth printing of this manual, which was first completed in 1966. The format remains in two parts – the standards and commentary. However, with this edition, these two have been brought together and aligned. The standards are on one side of the page and the commentary on the other providing for convenient reference. This revision was undertaken to update the manual to current standards.

The late William E. Dean of Howard Needles Tammen Bergendoff and previously retired as Florida State Bridge Engineer, wrote the first manual. It was then reviewed by the PCI Technical Activities Committee and edited by PCI staff. After three years of experience with the PCI Plant Certification Program, the manual was revised and printed in the familiar blue hardback cover in 1970. The second edition in 1977 was developed by the PCI Plant Certification Committee to update references and standards as well as incorporate certain revisions. The third edition in 1985 was developed and written by the consulting firm of Ross Bryan Associates, Inc., under contract to the Institute. The PCI Plant Certification Committee developed this fourth edition. Committee members working on the 4th edition were as follows:

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Lee Lawrence of Wiss, Janney, Elstner Associates, Inc., for accomplishing final editing.

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# **INTRODUCTION**

## **MNL-116, Fourth Edition**

The information in this manual is intended to serve as standards for quality control for the manufacture of precast and prestressed 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 manual was developed for plant-produced, precast concrete members, or precast, prestressed concrete members manufactured by the process of pretensioning, post-tensioning, or a combination of the two methods. The principles established herein are, however, applicable to site-cast precast concrete or prestressed concrete.

The manual was written by or under the direction of the PCI Plant Certification Committee. Pertinent information and requirements have been obtained from publications and standards of the Precast/Prestressed Concrete Institute (PCI), American Concrete Institute (ACI), Portland Cement Association (PCA), U.S. Bureau of Reclamation, and other agencies. This, combined with experience gained through more than 30 years of operation of the PCI Plant Certification Program, has contributed to the development of the manual.

The fundamental intent of this manual is to provide a basis for establishing a satisfactory quality control program for general precast 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 that appropriately satisfies the project requirements for intended use and economics of the product.

Satisfactory conformance with the Standards in this manual is required for certification in the PCI Plant Certification Program for the Bridge and Commercial (Structural) Product Groups. For an explanation of the Program requirements and procedures, see Appendix F, *Certification Programs*.

The Standards and Commentary portions of this manual are presented in a side-by-side column format; with the Standards placed in the left column and the corresponding Commentary 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.

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

## **INTRODUCTION to MNL-116, Fourth Edition**

### **SPECIAL FINISHES**

Standards for structural precast concrete products that are produced with architectural finishes and in accordance with the structural tolerances in this manual, are included at the end of each Division. Examples of such products are exposed columns and spandrel beams used on the exterior of parking structures.

At the end of each Division, only those Articles that pertain to the application of special finishes are listed. The special provisions are identified with an "A" preceding the Article number. **The criteria established in this manual govern except as specifically modified by these special provisions for architectural finishes.** The Article numbers are the same as the corresponding Articles in the main portion of the Standards. Where a special provision for architectural finishes does not have a matching Article for basic structural products, the provision is placed at the end of an Article or the Division with numbering continued sequentially.

Conformance with these additional Standards is recognized in the PCI Plant Certification Program by certification in two product categories. The Product Categories are designated as "Bridge Architectural" (BA), or "Commercial Architectural" (CA) within the Bridge Products and Commercial (Structural) Products Groups. For a description of these Groups, see Appendix F, *Certification Programs – Product Groups and Categories*.

This manual incorporates proven standards of practice. It contains requirements necessary to achieve an acceptable level of quality, but not the means or methods for doing so. The requirements of the manual are not intended to be applied in a manner that is restrictive to the development of individual plant techniques or innovation. As new materials and processes are developed, their application should be considered within the scope and intent of these Standards. The information contained in the Commentary is not part of the Standards and shall not be used in judging quality control or production procedures.

***Note: The production of precast concrete may involve hazardous materials, operations, and equipment. This manual does not 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 requirements.***

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

**Bleeding** – A form of segregation in which some of the water in a mix 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.

**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.

**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.

**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.

**Deflected Strand** – Strand that is deflected from a straight-line position in a member to enhance the moment-resisting capacity of the member. Deflected strand may be spaced apart or bundled together. If bundled at a point, the strand must be splayed-out from the bundle to the end of the member to develop bond on each strand.

**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.

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

**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.

**Form** – The container or surface against which fresh concrete is cast to give it a desired shape; sometimes used interchangeably with mold. (The term “mold” is used in this Manual for custom-made forms for specific jobs while “form” is used for standard forms or forms of standard cross section.)

**Formed surface** – A concrete surface that has been cast against formwork.

**Form release agent** – A substance applied to the 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 mix 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.

**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.

**Harped strand** – Strand partially tensioned in the lowest position along the length of the member and subsequently lifted or harped at the ends of a member to enhance the moment capacity at the center of the member. This can reduce the applied stresses at the end of the member by reducing the total amount of prestress.

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

**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.

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

**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 mix containing only the cement and fine aggregates (sand).

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

**Mold** – See “Form”

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

**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.

**Post-tensioning** – A method of prestressing concrete whereby the tendon is kept from bonding to the plastic (wet) 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 is 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)** – All those planned or systematic actions necessary to ensure that the final product or service will satisfy given requirements for quality and perform intended function.

**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.

**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** – See “Surface Retarder”

**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.

**Rustication** – A groove in a panel face 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 face, including release agent, adhere to the concrete. Some probable causes are an excessively rough form 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 mix, insufficient fines, water in the form 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 tendency for the coarse particles to separate from the finer particles during handling. 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, the mortar and wetter material rise to the top. In aggregate, the coarse particles roll to the outside edges of the stockpile.

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

**Set-up** – The process of preparing molds or forms 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.

**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.

**Specially finished structural precast concrete** – A product fabricated using forms and techniques common to the production of structural elements as defined in MNL-116 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.

**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.

**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.

**Stripping** – The process of removing a precast concrete element from the form 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.

**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.

**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.

**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.

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

**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** – The ease with which a given set of materials can be mixed into the concrete and subsequently handled, transported, placed, and finished with a minimum loss of homogeneity.

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# **DIVISION 1 - QUALITY SYSTEM**

## **Standard**

## **Commentary**

### **1.1 Objective**

Quality control shall be an accepted and functioning part of the plant operation. Overall product quality results from individual as well as corporate efforts. 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 corporate 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.

### **C1.1 Objective**

The general objective of this manual is to define the required minimum practices for the production of precast concrete units and for a program of quality control.

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

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

The use of a written Plant Quality System Manual requires an initial effort by plant management for development of the document. It further requires periodic updating to establish new practice guidelines for addressing the

**Standard****Commentary**

The Plant Quality System Manual 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 non-conformances, corrective actions, and response to customer complaints.
- d. Plant facilities in the form of a plant layout that notes allocation of areas, services, machinery, and equipment.
- e. Purchasing procedures for quality control compliance that includes project specification review for specific requirements.
- f. Identification of training needs and provisions for training personnel in quality assurance 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 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

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 Plant Quality System Manual.

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. Adequate inspection personnel to ensure review of all materials and processes.
- b. Clearly defined responsibilities and required functions for each inspector.
- c. Management commitment to supporting the quality assurance program and establishing a uniform standard of quality in the plant.
- 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 on a weekly basis 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*.

**Standard****Commentary**

- dimensions.
- e. Procedures for, and inspection of batching, mixing, placing, consolidating, curing, and finishing concrete.
  - f. Procedures for, and inspection of concrete repair, handling, storing, and loading of finished products.
  - g. Inspection of the placement and quantity of reinforcement, cast-in-place appurtenances, and block-outs.
  - h. Inspection of tensioning operations to ensure conformance with specified procedures.
  - i. Mix design preparation and evaluation.
  - j. Sampling and testing of materials and fresh concrete.
  - k. Inspection of detensioning and stripping procedures.
  - l. Inspection of finished products for conformance with the shop drawings, and other project requirements, such as approved samples when stipulated.
  - m. Repair procedures for non-compliant conditions.
  - n. Preparing and maintaining complete quality control records.
  - o. 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. These include, but are not limited to:

- a. A corporate standard of quality.
- b. A written Plant Quality System Manual which establishes a uniform order or practice for all manufacturing operations.
- c. Personnel, whose primary function is quality control, with direct 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 to ensure compliance with the required codes, standards, specifications, and in-plant performance requirements.

**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 product should understand that management supports the production of quality products.

**Standard****Commentary****1.3 Personnel****C1.3 Personnel****1.3.1 General****C1.3.1 General**

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

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.

At least one individual in the plant organization shall be certified as a Level II Technician/Inspector in the PCI Quality Control Personnel Certification program.

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 Technician.

**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 for precast concrete elements and be competent to review designs prepared by others.

Engineering personnel should review the design of precast concrete elements prepared by the engineer of record. The precast engineer should have the ability to solve problems and devise 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 for elongations, measurements for camber and deflections, compensations for operational stress variations, and any other functions related to prestressing that may affect the quality 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 *PCI Drafting Handbook – Precast and Prestressed Concrete, MNL-128*.

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

**Standard****Commentary****1.3.4 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 such as approved samples when stipulated.

**1.3.5 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 control personnel shall be responsible for 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 forms.
- 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 and cast-in items.
- e. Inspecting tensioning operations to ensure conformance with specified procedures.
- f. Preparing or evaluating mix designs.
- g. Taking representative test samples and performing all required testing.
- h. Inspecting finished products for conformance with the shop drawings and other project requirements, such as approved samples, when required.
- i. Preparing and maintaining complete quality control records.

**1.4 Design Responsibilities****1.4.1 General****C1.3.4 Production**

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.

**C1.3.5 Quality Control**

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 satisfy the desired level of quality.

Quality control personnel should observe and report any changes in plant equipment, working conditions, weather, and other items that have the potential for affecting the quality of products.

**C1.4 Design Responsibilities****C1.4.1 General**

**Standard****Commentary**

The responsibilities of the architect/engineer and the precast manufacturer are subject to a contractual relationship with the owner. The manufacturer shall be responsible for translating the project requirements into samples (as required), shop drawings, tooling, manufacturing procedures, and installation procedures in accordance with the appropriate provisions of the contract documents.

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 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 *Code of Standard Practice for Precast Concrete – PCI Design Handbook, MNL-120*.

When conditions are known, the manufacturer 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.

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

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

The engineer of record should recommend 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 precast manufacturer should determine any additional requirements imposed by manufacturing and handling procedures.

**1.4.2 Shop Drawings****C1.4.2 Shop Drawings**

The manufacturer shall prepare and submit drawings for approval, as required, in general accordance with the *PCI Drafting Handbook – Precast and Prestressed Concrete, MNL-128*, and the project specifications. Production drawings shall be prepared to convey all pertinent information necessary for fabrication and inspection of the precast concrete products.

The primary function of precast concrete shop (erection and production) 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.

**1.5 Project Samples****C1.5 Project Samples****1.5.1 General****C1.5.1 General**

When required by project specifications, finish samples shall be prepared and submitted for approval.

For descriptions of typical surface treatments of structural concrete members, refer to Appendix C, *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 expressly withheld.

**Standard****Commentary**

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

**1.5.2 Size and Shape**

Samples shall reflect the shape of the actual unit. Flat samples shall only be used for flat castings.

The size of samples shall reflect the relationship to the size of aggregate, finish, shape, and casting techniques.

**1.5.3 Identification**

All samples shall be clearly identified.

**1.5.4 Visual Mock-ups and Initial Production Approval of Finishes**

When required by project specifications, a mock-up consisting of a full-scale portion of a unit shall be used for initial production approval. Previously completed project units, mock-ups, or samples that are similar, may be used for initial production approval of products.

The number of approved samples shall be sufficient for establishing the range of acceptability with respect to surface variations, defects, and overall appearance.

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

Typical structural concrete will vary in color from batch to batch. When uniformity in color or texture is desired, the requirements should be clearly specified in the project documents.

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. Samples should be made as nearly as possible in the same manner intended for the actual units.

**C1.5.2 Size and Shape**

For non-planar, curved, or other complex shapes, a flat-cast sample may not represent the anticipated appearance of the final product.

**C1.5.3 Identification****C1.5.4 Visual Mock-ups and Initial Production Approval of Finishes**

Small 12-in. (300-mm) square samples do not generally provide an adequate representation of the actual product. When mock-up units are not used, the manufacturer should request the architect/engineer or owner to inspect and approve (sign and date) the initial production units. Larger production samples are more representative of the entire structure and will help eliminate uncertainties that the architect/engineer or owner may have.

Multiple samples of a sufficient size may be used to establish a range of acceptability. When specified, the acceptability of repair techniques for chips, spalls, or other surface blemishes should also be established with these samples.

***DIVISION 1***

***QUALITY SYSTEM***

**Standard**

**Commentary**

Approved samples shall be kept at the manufacturing facility and shall be used to monitor the acceptability of the production panels.

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

# **DIVISION 1-QUALITY SYSTEM**

## **PROVISIONS FOR SPECIAL FINISHES**

The following Articles, designated with an “A” prefix, apply to structural products with an architectural finish requirement. Conformance with the requirements of the Articles is required as part of certification in the Product Categories “Bridge Architectural” (BA), or “Commercial Architectural” (CA) within the Bridge Products and Commercial (Structural) Products Groups. For a description of these Groups, see Appendix F, *Certification Programs – Product Groups and Categories*.

The criteria established in this manual govern except as specifically modified by these provisions for the special class of products defined above.

The Article numbers are the same as the corresponding Articles in the main portion of the Standard. Where a special provision for architectural finishes does not have a matching Article in the main portion of the Standard, the provision is placed at the end of an Article or the Division with numbering continued sequentially.

### **Standard**

### **Commentary**

#### **A1.5 Project Samples**

#### **AC1.5 Project Samples**

##### **A1.5.1 General**

##### **AC1.5.1 General**

Before production of units, the precast concrete manufacturer shall prepare and submit for approval, a representative sample or samples with the required color and texture. If the back face of a precast concrete unit is to be exposed, samples of the workmanship, color, and texture of the backing shall be shown. Changes in the source of materials or mix proportions shall require approval of new reference samples. When specified, or if significant variations in appearance are anticipated, samples showing the expected range of variations shall be supplied.

All project samples should be submitted promptly for early acceptance to provide for timely material procurement and production of units.

If small samples are used to select the aggregate color, the architect or owner should be made aware that the samples may not be representative of the larger units. Large surface areas of structural 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.

##### **A1.5.4 Visual Mock-ups and Initial Production Approval of Finishes**

##### **AC1.5.4 Visual Mock-ups and Initial Production Approval of Finishes**

When new shapes, materials, or finishes are used, the precaster shall utilize a mock-up consisting of a full-scale portion of a unit for initial production approval.

The samples shall be stored adjacent to each other and outdoors to allow proper lighting (sun and shade) for daily comparisons with the production units.

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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 should be maintained in good 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, 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 encourages workers' safety and health. It shall be patterned after the OSHA Safety and Health Standard–29CFR 1910 and/or other jurisdictional safety and health standards.

#### C2.1.2 Plant Safety

A safety program is an important element of any production operation. PCI 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 general safety practices as related to the precast concrete industry and existing federal 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.** Safety rules designed to help employees avoid injury.
3. **Training.** A training program to ensure that employees are instructed in safe 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 customize for their facilities, products, and operations.

### 2.2 Production and Curing Facilities

### C2.2 Production and Curing Facilities

#### 2.2.1 Area Requirements

The production and curing area(s) shall be designed for controlled production of quality structural precast concrete units. The area(s) shall be of adequate size in relation to the volume and characteristics of the products manufactured for a well-organized, continuous operation.

#### C2.2.1 Area Requirements

In design of the areas, consideration of production flexibility, flow patterns, health, and safety should be made. The casting area should provide flexibility in planning and spacing of the forms. This area should facilitate efficient movement of workers, materials, and equipment. If required, facilities should be provided for post-tensioning or pretensioning. Provisions should be made to control the temperature with reasonable accuracy, as form release agents and other chemicals may react differently under varying temperature and humidity ranges. Adequate lighting should be provided for all operations.

**Standard****Commentary**

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

**2.2.2 Form Fabrication**

Form fabrication facilities shall be tooled to provide for form construction at a sufficient level of accuracy to produce the product within required tolerances.

Forms shall be stored in a manner that provides protection from dimensional, surface, or structural damage.

For the fabrication of precast/prestressed structural products, self-stressing forms, bed abutments, and anchorages shall be designed by qualified engineers. Information on the capacity of each bed and self-stressing form, in terms of allowable prestress force and corresponding center-of-gravity above the form base, shall be kept on file.

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

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

To meet the provisions of Division 4, it may be necessary to provide heating and/or proper ventilation for the casting area and the forms depending on the geographic location of the plant.

**C2.2.2 Form Fabrication**

Form 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 plastic forms should be stored within the manufacturer's recommended temperature range and away from the production areas.

The design of prestressing forms 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. Foundations should be designed to prevent undesirable movement.

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

Release agents and other chemicals generally have a reasonably long and stable storage life. However, such materials may be susceptible to damage from extreme temperature changes.

Certain weather conditions can affect the performance of water-based release agents or other chemicals. Such release agents generally cannot be used in freezing conditions. Even at temperatures slightly above freezing, some water-based products begin to thicken which may increase surface air voids and reduce performance.

## **DIVISION 2**

## **PRODUCTION PRACTICES**

### **Standard**

### **Commentary**

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

The oils in some release agents have a critical emulsifier content. Dilution makes the emulsion unstable and causes poor performance.

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

#### **C2.2.4 Hardware Fabrication and Storage**

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

Stainless steel hardware shall be protected from contamination with other metals during storage and fabrication. Stainless steel hardware shall only be handled with non-metallic or stainless steel 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. Low hydrogen shielded metal arc welding (SMAW) electrodes shall be stored in the original airtight containers or at the recommended elevated temperature in a suitable oven. Once containers are opened, welding electrodes and wires shall be kept in dry, heated storage in accordance with the manufacturer's recommendations.

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

If an outside supplier fabricates hardware, that supplier shall furnish records of compliance to specification requirements and material mill certificates.

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

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

The concrete handling equipment shall be capable of delivering concrete from the mixer to the form as follows:

1. In sufficient quantities to avoid undue delays in placement and consolidation.
2. Without segregation of aggregate and paste.
3. With uniform consistency.

**Standard****Commentary**

4. With ease of discharge into forms.
5. With equipment capable of being thoroughly cleaned.
6. With consideration for concrete temperatures.

The casting area shall be supplied with the necessary equipment in good operating condition to ensure proper placement, consolidation, and finishing of the concrete. Provisions shall be made to supply adequate and safe power for electrical equipment. Before a vibratory unit is used, it shall be inspected to verify that it is working properly.

Internal, external, and surface type vibrators may be used, individually or in various combinations, depending on factors such as the size and shape of the product.

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

The plant shall be capable of maintaining a minimum concrete temperature of 50°F (10°C) during the initial curing cycle (prior to stripping).

Configuration of curing facilities vary with the product type, size, and curing methods.

When moist curing is used, facilities shall provide a well-drained area. Adequate covering shall be provided to maintain the required relative humidity and temperature around the product.

The degree and rate of heating for accelerated curing shall be established based on the volume of concrete, stripping or transfer strength requirements, length of the curing cycle, and the effectiveness of the heat enclosure. The heat source and the distribution system shall be protected to prevent operational hazards and shall provide uniform controlled heat for each unit or series of units being cured. Heat enclosures shall not damage the product or adversely affect the uniformity of heat distribution to the units.

Temperature measuring devices should be positioned to record the maximum and minimum anticipated concrete temperature.

Equipment shall be available to record the time and temperature relationship for the accelerated curing cycle. The number of thermometers or thermocouples shall be sufficient to monitor the uniformity of heat supplied to the product.

One temperature measuring device should be located near the concrete compression test specimens if cured with the product, or at a location farthest from the heat source, when a master-slave control is used.

For each set of strength specimens cast: (1) within one hour of each other; (2) with a similar concrete mix, and (3) cured under the same conditions, one temperature record for the represented product is adequate.

**Standard****Commentary****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.

**C2.2.7 Handling Equipment**

The type and capacity of handling equipment utilized for handling materials and products will depend on size, configuration, and the operating conditions.

**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 settlement under all weather conditions, soiling, and damage of the product. Refer to Article 2.7.3 for dunnage requirements.

**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, units should not be stored on frozen ground without proper safeguards to prevent settlement when the ground thaws. The storage area should be inspected after hard rains or large snowmelts for washouts and other damage.

Storage racks shall be designed to safely store product to prevent units from tipping over and damaging adjacent units. Storage racks such as "horses," A-frames, and vertical racks shall be well constructed to minimize warping, bowing, chipping, or cracking of the products. The plant engineer shall review storage systems to verify safe load capacity. Where necessary, such storage equipment shall be protectively coated to avoid staining or discoloration of the finished products.

**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 accordance with AWS D1.1. Welders qualified in accordance with AWS D1.1 and D1.4 shall perform all welds. Qualified engineers or quality control personnel shall write welding procedure specifications (WPS) for structural steel.

Welding current 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 be as shown on the shop drawings. Unspecified welds shall not be used without approval of the precast engineer.

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**Commentary**

Surfaces to be welded and surfaces adjacent to a weld shall be uniform, free from fins, tears, cracks, and other discontinuities. Potential contaminants such as loose or thick mill scale, slag, rust, moisture, grease, and other foreign materials that may prevent proper welding or produce objectionable fumes shall be removed. Mill scale that can withstand vigorous wire brushing, a thin rust-inhibitive coating, or anti-spatter compound does not require removal prior to welding.

The preheat requirements of insert plates shall be in accordance with Table 2.3.1. Welding shall not be done when the temperature in the immediate vicinity of the weld is below 0°F (-18°C). When the insert plate temperature is below 32°F (0°C), the plate shall be preheated to a minimum temperature of 70°F (21°C). This temperature shall be maintained throughout the entire welding process. Three inches of the insert plate, in each direction around the weld, shall be preheated to at least the minimum required temperature.

Temperature sensitive crayons are frequently used to give an approximate preheat temperature indication. This measurement usually should be made within one inch (25 mm) of the weld on the base metal. Crayon marks should never be made directly on the weld due to possible contamination of the weld region.

**Table 2.3.1 Minimum Preheat Temperatures for Insert Plates**

Thickest Section at Point of Welding, in. (mm) for A36, A500, Grades A and B, and A572, Grades 42 and 50 <sup>(2)</sup>	Minimum Temperature <sup>(1) (2) (3)</sup> °F (°C)
Up to 3/4 (19)	None
Over 3/4 through 1-1/2 (19-38.1 incl)	150 (66)
Over 1-1/2 through 2-1/2 (38.1-63.5 incl)	225 (107)
Over 2-1/2 (63.5)	300 (150)
(1) Minimum temperature required when using shielded arc welding with low hydrogen electrodes, submerged arc welding, gas metal arc welding or flux cored arc welding. (2) If the steel specification for the insert plate or welding process being used is not shown, refer to Table 3.2 of AWS D1.1 for preheat requirements. (3) This must be compared to the preheat requirements for the reinforcing bar. The higher of the two requirements should be applied.	

Slag from each pass shall be completely removed before depositing the next weld pass to avoid porosity and slag entrapment. Slag shall be removed from all completed welds. The weld and adjacent base metal shall be cleaned by brushing or other suitable means. Tightly adhered spatter that remains after the cleaning operation is acceptable.

Accessible welds of corrosion protected material (galvanized or painted) shall be touched up after welding. Zinc-rich paint shall be brush or spray applied to a thickness of approximately 0.004 in. (0.10 mm) or shall be in conformance with ASTM A780.

When galvanized steel is welded, some of the zinc coating is volatilized on each side of the weld. While a thin layer of zinc-iron alloy remains, the corrosion resistance is reduced. In the case of zinc-rich painted steel, welding causes decomposition of the paint film, which is burned off for

**Standard****Commentary**

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One of the following procedures shall be used for welding galvanized steel:

1. Removal of galvanizing on surfaces to be welded.
2. Use of welding procedures for galvanized base metal as described in D1.4, Section 5.6, and qualified by test in accordance with AWS D1.1.

When welding stainless steel plates to other stainless steel, the procedure outlined in AWS D1.6 shall be followed. When welding stainless steel to low carbon steel, procedures should account for the stainless steel characteristics that differ, such as higher thermal expansion and lower thermal conductivity. Welding of stainless steel shall be in accordance with AWS B2.1, AWS A5.4, AWS D1.1, and AWS D1.6. Welding of stainless steel shall be done by qualified welders familiar with the welding requirements of these alloys. Preheating or postheating is not necessary when only stainless steel is welded.

some distance on each side of the weld. The width of the damaged zone will depend on the heat input.

Removal of zinc, where weld is to be placed, is the most conservative approach in welding galvanized steel. If removed, the welding procedures will then be the same as for uncoated steel. Zinc can be removed by burning with an oxygen fuel gas torch, by shot blasting with portable equipment or grinding with an abrasive disc. In general, manual metal arc welding procedures for galvanized steel are similar to procedures for welding uncoated steel. However, welding of galvanized steel generally requires that the welder receive specialized training. In addition, qualification of the welder and welding procedure using the thickest coating anticipated is strongly recommended.

Stainless steels have many properties that differ from those of carbon or other steels. The differences become more pronounced as the chromium content increases. For example:

1. Thermal conductivity is much lower making it more susceptible to localized overheating and distortion when welded.
2. Thermal expansion is higher which tends to increase distortion and results in higher weld stresses during cooling.
3. The resistance to oxidation is reduced when heated to temperatures near the melting point in the presence of air. This causes highly refractory chromium oxide to form, which prevents cutting with an ordinary oxyacetylene torch. Accordingly, when welding stainless steels, the molten metal must be well protected from the air.
4. Some martensitic alloys (with high carbon content) 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.

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 of austenitic stainless steel, precautions are necessary to avoid weld bead cracking and distortion that may cause cracking of the concrete. The following procedures may be used to minimize these problems: lower weld current settings; skip-weld techniques to minimize heat concentration; use of copper backup chill bars or other cooling techniques to dissipate heat; tack welding to hold the parts in alignment during welding and small weld passes.

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A method for cutting stainless steel shall be used that produces a clean, smooth edge.

Mechanical or power cutting processes such as plasma arc, laser cutting, or other appropriate methods should be used for stainless steel. Stainless steel cannot be cut smooth with an ordinary oxyacetylene torch.

The edges of a stainless steel weld joint that is cut with an oxyacetylene torch shall be cleaned by machining or grinding to remove surface contamination, such as iron. Surfaces to be welded shall be sanded smooth, not ground, and all blue heat tint removed. Parts to be joined shall also be free of oil, grease, paint, dirt, and other contaminants.

Cleaning of stainless steel to be welded is important. Contamination from grease and oil can lead to carbonization in the weld area with subsequent reduction of corrosion resistance. Post weld clean up 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. These particles will rust and cause staining if not removed by chemical cleaning.

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.

This will prevent martensite formation while at the same time preserve residual amounts of ferrite, which counteract the tendencies for hot cracking (at the time of welding) even under conditions of severe restraint.

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

Qualified engineers or quality control personnel shall write welding procedures for reinforcing bars. Welding of reinforcing bars shall be executed considering steel weldability and proper welding procedures, whether performed in-plant or by an outside supplier.

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 chemical analysis limits the applicable welding procedures and sets preheat and interpass temperature requirements. Weld properties are specifically excluded from the ASTM A615, A616, and A617 specifications. Most reinforcing bars that meet ASTM A615, Grade 60 (420), will require preheating. A615, Grade 40 (300) bars may or may not require preheating. ASTM A706 bars are specially formulated to be weldable. Accordingly, the specification contains chemical composition requirements and calculation of the carbon equivalent.

Welding procedures shall be in conformance with AWS D1.4 using shielded metal arc (SMAW), gas metal arc (GMAW), or flux cored arc (FCAW) processes. 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

AWS D1.4 indicates that most reinforcing bars can be welded. However, stringent preheat and other quality control measures are required for bars with a high carbon equivalence. Except for welding shops with proven quality control procedures that meet AWS D1.4, it is recommended that the carbon equivalence be less than 0.45

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**Commentary**

to determine the carbon equivalence (C.E.) and the preheat requirements. Minimum preheat and interpass temperatures for welding or reinforcing bars shall be in accordance with Table 2.3.2, using the highest carbon equivalent number of the base metal.

% for No. 7 (22) and larger bars, and 0.55% for No. 6 (19) and smaller bars.

Proper welding procedures are critical for reinforcing steel due to a relatively high carbon content. Temperature-sensitive crayons or other appropriate methods should be used to determine approximate preheat and interpass base metal temperatures.

**Table 2.3.2 Welding Reinforcing Bars**

Carbon Equivalent <sup>4</sup> Range, %	Size of Reinforcing Bar	Minimum Preheat and Interpass Temperatures <sup>1, 2, 3, 6</sup>	
		°F	°C
0.40 max.	Up to 11 (36) inclusive 14 (43) and 18 (57)	None <sup>5</sup> 50	10
0.41 – 0.45 inclusive	Up to 11 (36) inclusive 14 (43) and 18 (57)	None <sup>5</sup> 100	40
0.46 – 0.55 inclusive	Up to 6 (19) inclusive 7 (22) to 11 (36) inclusive 14 (43) and 18 (57)	None <sup>5</sup> 100 200	40 90
0.56 – 0.65 inclusive	Up to 6 (19) inclusive 7 (22) to 11 (36) inclusive 14 (43) and 18 (57)	100 200 300	40 90 150
Above 0.66	Up to 6 (19) inclusive 7 (22) to 11 (36) inclusive	300 400	150 200

**Notes:**

- When reinforcing steel is to be welded to main structural 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, with measures taken to satisfy the preheat requirements for both. If this is not possible, welding shall not be used to join the two base metals.
- 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. The preheating shall be performed in a manner that ensures 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 desired minimum temperature. If multiple passes are required to make the weld, the area shall be reheated during the time between passes (interpass). Preheat and interpass temperatures shall be sufficient to prevent crack formation.
- After welding is complete, bars shall be allowed to cool naturally to ambient temperature. Accelerated cooling is prohibited.
- Where it is impractical to obtain chemical analysis, the carbon equivalent shall be assumed to be above 0.66% except for ASTM A706 bars.
- 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 temperature during welding.
- Temperature sensitive crayons shall be used for determining approximate preheat and interpass temperatures.

A higher carbon content generally means a susceptibility to embrittlement after the weld begins to cool. If a weld cools too rapidly, a very brittle form of steel called martensite forms just outside the weld zone. This material is subject to fracture upon impact.

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

$$C.E. = \%C + \%Mn/6$$

If mill test reports are not available, chemical analysis

**Standard****Commentary**

may be made on bars representative of the bars to be welded. If the chemical composition is not known or obtained, the following shall apply:

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 400° F (200° C).
3. For all ASTM A706 bar sizes, use Table 2.3.2 C.E. values of 0.46% 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, coatings, or other foreign materials 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 does not require removal prior to welding.

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.

Welding shall not be performed when: the ambient temperature is lower than 0° F (-18° C); when surfaces to be welded are exposed to inclement weather; if the wind velocities are greater than five miles per hour (eight kilometers per hour); or when welders are exposed to inclement conditions.

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 Section 5.6 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 for uncoated reinforcing bars. 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 shall be applied to the finished joint to restore the corrosion resistant properties of the coated bars.

The galvanized coating should be removed with oxyfuel gas flame, abrasive shot blasting, or other suitable means. Zinc-rich, epoxy paint, or other suitable coatings may be used to protect the welded joint.

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For reinforcing bars, including ASTM A706 bars, tack welds that do not become a part of permanent welds shall not be made unless shown on the approved shop drawings. Tack welds shall be made in accordance with all the requirements of AWS D1.4, i.e., preheating, slow cooling, use of proper electrodes, and the same quality requirements as permanent welds.

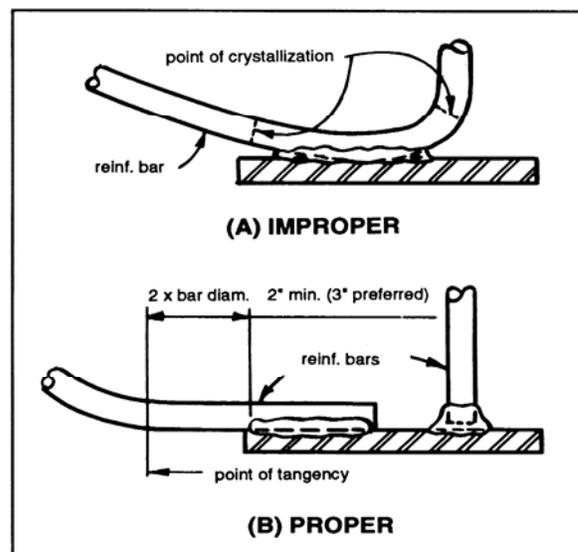
Tack welding, unless done in conformance with AWS D1.4, may produce crystallization (embrittlement or a metallurgical notch) of the reinforcing steel in the area of the tack weld. Tack welding seems to be particularly detrimental to ductility (impact resistance) and fatigue resistance. To a lesser extent, it is detrimental to the static yield strength and ultimate strength. Where a small bar is tack welded to a larger bar, a detrimental “metallurgical notch” effect often is exaggerated in the large bar. Fast cooling under cold weather conditions is likely to aggravate this effect.

Tack welding shall be performed without significantly diminishing the effective steel area, unless the bar is one-third larger than required. A low heat setting shall be used to reduce undercutting of the reinforcing bar.

There is essentially no difference in the potential for embrittlement and chemical change that the material undergoes during tack welding as compared to a larger type of weld. Therefore, if the reinforcing steel requires the use of preheat and low hydrogen electrodes, these measures should also be employed when tack welding. Tack welding should be limited to straight sections of bars and within the limitations indicated in the shop drawings.

Reinforcing bars that 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. When reinforcing steel is welded to structural steel members, the provisions of AWS D1.1 shall apply to the structural steel component. When joining different grades of steels, the filler metal shall be selected according to the requirements of the lower strength base metal.

When bars are bent cold, the sensitivity to heat is increased. Subsequently, the application of too much heat will cause the bars to crystallize and result in unpredictable behavior at the bend. Therefore, it is necessary to keep welds away from cold bends as shown in Figure C2.3.2, Improper and proper methods of welding reinforcing bars. While AWS D1.4 suggests allowing a cold bend at two bar diameters from a weld, experience shows that a minimum distance of 2 in. (50 mm) (3 in. (75 mm) preferred) is better for the small bars commonly used in precasting.



**Fig. C2.3.2. Improper and proper methods of welding reinforcing bars.**

**Standard****Commentary****2.3.3 Stud Welding**

Headed studs and deformed bar anchors used for anchorage shall be welded in accordance with AWS D1.1 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 the welding operation. The base metal shall not be painted, galvanized, or cadmium-plated prior to welding. The thickness of the plates to which the studs are attached shall be at least 1/2 of the diameter of the stud.

The arc shields or ferrules shall be kept dry. Arc shields that show signs of surface moisture shall be oven dried at 250° F (120° C) for two hours 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, the guns shall be interlocked so that only one gun can operate at a given time. This is to ensure the power source has fully recovered from making the previous weld before the next 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 the temperature of the base metal is below 32° F (0° C), one additional stud per 100 studs welded, shall be tested by methods specified in Article

**C2.3.3 Stud Welding**

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

The areas to which the studs are to be welded shall be free of scale, rust, moisture, or other deleterious materials to the extent necessary for obtaining satisfactory welds. These areas shall be cleaned by wire brushing, scaling, prick punching, or grinding.

Low-carbon (mild) steels can be stud welded with no major metallurgical problems. The upper carbon limit for base plate steel that can be arc stud welded without preheating is 0.30%.

Generally, high-strength low alloy steels can be satisfactorily stud welded when the carbon content is 0.15% or lower. If the carbon content exceeds 0.15%, preheating may be necessary.

Most classes of stainless steel can be stud welded. However, only the austenitic stainless steels, such as the 300 grades (except 303), are recommended for general stud welding applications.

**Standard****Commentary**

6.2.3(9). One additional exception is that the angle of testing shall be approximately 15 degrees. This is in addition to the first two studs tested for each start of a new production period or change in set-up.

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

1. Surfaces to be welded and surfaces adjacent to a weld shall be free from loose or thick scale, slag, rust, moisture, grease and other foreign materials that may 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.
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 or 3/16 in. (4 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****2.4.1 Materials and Construction**

Forms shall be designed to prevent damage to the concrete from: (1) restraint as the concrete shrinks; (2) stripping operations; and (3) dimensional changes due to pretensioning.

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

Forms shall be sufficiently dimensionally stable to produce the required tolerances. Repeated use of forms shall not affect the dimensions or planes of the forms beyond allowable tolerances.

3. If medium and high-carbon base plate material is 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.

**C2.4 Forms****C2.4.1 Materials and Construction**

The overall quality of the project starts with forms capable of allowing the production personnel to make units that meet the specifications requirements with ease and accuracy.

Forms for structural precast concrete can be made of various materials such as plywood, concrete, steel, plastic, polyester resins reinforced with glass fibers, plaster, or a combination of these materials. For complicated details, forms made of plaster, elastomeric rubber, foam, plastic, or sculptured sand may be used. These forms are often combined or reinforced with wood or steel depending on the size and complexity of the unit to be produced.

Typically, the form fabrication and set-up tolerances should be one-half of the product tolerances.

The form design should account for the special requirements of precast concrete products. Sharp angles

**Standard****Commentary**

When the form is used to carry the prestressing force prior to transfer of stress to the product, it shall be sufficiently strong to withstand the force without buckling or wrinkling and maintain the required dimensional tolerances.

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

Forms shall be built sufficiently rigid to provide dimensional stability during handling. The assembled forms shall minimize leakage of cement paste.

Forms on a suitable foundation shall be capable of supporting their own weight and the pressure of the fresh concrete, without deflection or deformation in excess of product tolerances. Forms shall be sufficiently rigid to withstand the forces necessary for consolidating the concrete. Forms subjected to external vibration shall be capable of transmitting the vibration over a sufficient area in a relatively uniform manner, without flexing or plate flutter. The forms shall be designed to ensure that resonant vibrations imparted into localized areas are minimized.

and thin projections should be avoided whenever possible. Chamfers or radii at inside corners of the form should be used to minimize the possibility of chipping and spalling.

Forms should allow for shortening and movement of the precast concrete units during transfer of prestress and the application of heat when accelerated curing is used.

When selecting a release agent, the following information should be investigated:

1. Compatibility of the release agent with the form material, form sealer, or admixtures used in the concrete mix.
2. Compatibility with coatings to be applied to the formed surface of the units.
3. Required curing period. Some release agents require a curing period to prevent mixing of the release agent with the concrete.
4. The minimum and maximum time period in which the release agent is effective prior to and after concrete placement.
5. The effect of weather and curing conditions on the ease of stripping.
6. Uniformity of performance.
7. Environmental regulations regarding the use of volatile organic compounds (VOC).

Applying too much release agent can cause excessive surface dusting of the formed concrete surface. Mineral oil, oil-solvent based release agents, or paraffin wax should not be used on rubber or elastomeric liners, as the hydrocarbon solvent will soften the rubber. The recommendations of the form liner manufacturer should be carefully followed.

Forms should provide high rigidity, minimum deflection, and minimum movement of the form material between stiffeners.

**Standard****Commentary**

Forms 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 properly located and of the size and shape shown on the shop drawings. Blockouts shall be held rigidly in place within tolerance. Forming accessories shall allow for stripping without damage to the units.

Wood forms shall be sealed with suitable material to prevent absorption. The sealer manufacturer's recommendations for sealing shall be followed.

**2.4.2 Verification and Maintenance**

The form surfaces and dimensions shall be inspected in detail after form construction, before the first unit is cast, and after required modifications. A complete inspection of the first unit produced in the form shall be performed. Forms shall be cleaned and maintained in a manner consistent with project requirements.

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

**2.5 Hardware Installation**

Connection hardware and accessories, as stated below, shall be accounted and verified for proper size, type, finish, and location in accordance with the shop drawings:

1. anchors
2. inserts
3. plates

Sealing wood forms minimizes non-uniformity in surface finishes and will stabilize the form dimensions. The manufacturer's recommendations regarding application of the sealer should be followed. Some sealers may not be applied below a minimum temperature. An appropriate drying or curing time should be allowed.

**C2.4.2 Verification and Maintenance**

When a new form is placed into production a complete dimensional inspection should be performed. As a minimum, the main dimensions, warping, squareness, flatness, reveals, blockouts, and quality of the surface finish should be inspected for conformance with the project requirements. Fixtures and templates can aid in performing this inspection. The documentation of this inspection should be kept on file.

The forms 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 inspected on all sides of the form. The squareness of the form should be inspected by comparing diagonal measurements to the corners of the form. Discrepancies noted in form dimensional accuracy should be relayed to production personnel for correction.

**C2.5 Hardware Installation**

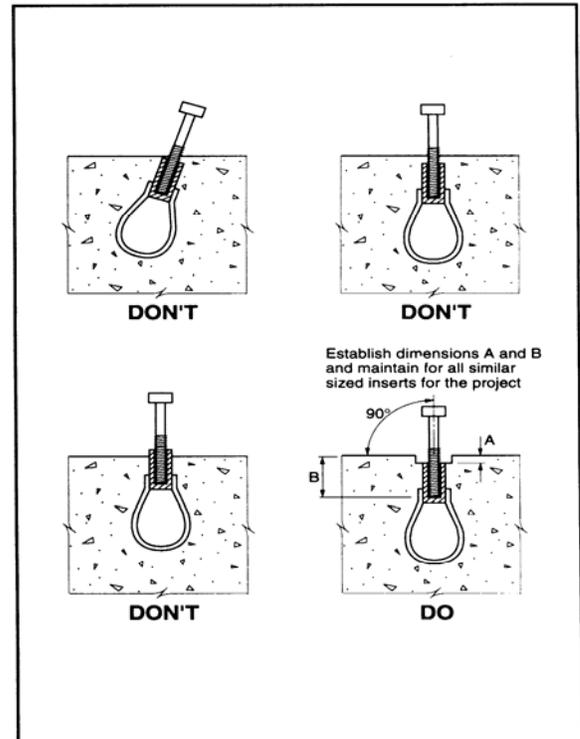
Inserts should be placed accurately. Variations in the depth of embedment, spacing, and distance from free edges can reduce the load capacity. The load capacity may also be reduced if the inserts are not positioned perpendicular to the bearing surface, or in proper alignment with regard to the applied force.

**Standard**

**Commentary**

- 4. angles
- 5. handling/lift devices

It is also important to place threaded inserts so that the depth of thread is constant for the same size insert throughout a particular job; otherwise, the erection crew may make mistakes in the field by not always engaging the full thread length. Utilization of one size and thread depth for inserts on a project helps to minimize the possibility of using the incorrect size and length of bolts. Proper and improper insert placement details are shown in Figure C2.5.1, Placing of inserts.



**Fig. C2.5.1. Placing of inserts.**

Hardware subjected to concrete placement and consolidation shall be held firmly in place by attachment to the form, reinforcement, or by jiggging.

The proper anchorage of the insert or hardware is critical. Careful placement of hardware to the required tolerances, including inclination of protruding bars or structural shapes is important. This helps to ensure proper alignment of the matching hardware and optimum load transfer.

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. This is provided the item(s) is not required to be hooked or tied to the reinforcement within the concrete and are maintained in the correct position until the concrete hardens. Such items shall be properly anchored to ensure full development of the design load. The concrete surface adjacent to the embedded item shall be properly finished for correct interfacing.

## **DIVISION 2**

## **PRODUCTION PRACTICES**

### **Standard**

### **Commentary**

If hardware anchors or reinforcing steel cannot be located as shown on the shop drawings, approval for revisions to the placement details shall be obtained from the precast engineer. Revisions of placement details shall be recorded.

Revisions to placement details should be coordinated with mating parts.

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.

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

Excessive honeycombing beneath the plate or angle may result in diminished structural capacity.

Voids in sleeves, inserts, and anchor slots shall be filled temporarily with removable material to prevent entry of concrete during casting. Inserts and sleeves shall be kept clean of dirt or ice by protecting 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 protected from damage and rust.

Stainless steel bolts shall be used to connect stainless steel plates or angles. Carbide inserts shall be used for high speed drilling of holes in stainless steel. Threaded parts of stainless steel bolts shall be lubricated with 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 electro-chemical (galvanic) reactions will occur or the surfaces are permanently protected against corrosion. Sleeves, pipes, or 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 used if the installation does not damage the structural integrity or finish of the unit.

Multiple component lifting devices shall be kept matched to avoid non-compatible 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.

**Standard****Commentary**

Treated or naturally deterioration-resistant lumber with an applied sealer shall be used if the lumber is to be cast in the concrete. The sealer shall be applied to prevent moisture migration from the concrete into the wood.

Placing wood in concrete, even if the wood is sealed, should be avoided due to the tendency of wood to swell under moist conditions. The stress induced by the swelling of the wood can cause cracking of the concrete.

Inserts on the exposed face of units shall be recessed to provide adequate cover of patching materials.

**2.6 Product Identification****C2.6 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.

Product identification may be made in the wet concrete, painted on the units, or with tags, provided the tags are securely fastened to the units. Product identification should remain legible while in storage.

**2.7 Product Handling****C2.7 Product Handling****2.7.1 General****C2.7.1 General**

Precast concrete units shall be handled in a manner as to avoid damage and excessive stresses. Units shall be handled and supported only by appropriate devices at designated locations. Lifting devices shall be inspected to ensure the locations conform to the shop drawings.

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

Lifting from threaded inserts shall be made with appropriate hardware. If inclined lifting lines are employed, the angle from the horizontal shall not be less than 45 degrees, unless specifically shown on 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.

The bolts used in handling inserts shall be of sufficient length to fully engage all threads. The extension of the bolt beyond the fully threaded position of coil inserts shall be in accordance with the manufacturer's recommendations. In addition, bolts shall be inspected for cracks, wear, deformations, or other defects. Bolts with defects shall be discarded.

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

Appropriate swivel bolt hardware shall be used when lifting is not axial to the intended load direction of the insert.

**Standard****Commentary****2.7.2 Stripping**

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

Removable inserts, fastenings, and form parts shall be released and/or removed prior to stripping. Care shall be exercised in removing the precast concrete unit from the form 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 the approved shop drawings or as approved by authorized personnel. Initial lifting from the form shall be made cautiously and gradually.

**2.7.3 Yard Storage**

The storage area shall be laid out in a manner to help ensure delivery and storage of the units without damage. Units shall be supported and stored on unyielding supports at the designated blocking point locations. The supports shall be on a firm, level, and well-drained surface. Unit identification marks shall be 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 properly supported.

Dunnage shall be placed between units, and between the units and storage devices. Dunnage material shall not cause damage, discoloration, or stains that are unacceptable for the project requirements.

**C2.7.2 Stripping**

A product that is stripped or detensioned prior to achieving adequate concrete strength can crack, spall, or lose bond between the strands and the concrete.

Proper rigging procedures should be established and documented. Methods of hooking to different types of lifting devices and permissible sling angles should be addressed in the plant procedures. When more than two lifting points are used, lifting should be rigged to ensure proper force distribution on the lifting devices.

Significant member stresses are often produced during stripping. Proper care should be taken to minimize stripping stresses to within acceptable limits.

**C2.7.3 Yard Storage**

Units are generally stored with two-point supports often spaced near the fifth point of the member. More than two supports can result in bridging over one or more of the supports due to differential settlement of the supports.

Proper member support during storage can minimize warping and bowing. Warping and bowing of units in storage are generally caused by temperature or shrinkage differentials, creep, and storage conditions. Warping and bowing cannot be totally eliminated; however, proper storage conditions can help to minimize such occurrences.

Panel units that are stored leaning on adjacent pads may induce an accumulation of stresses. The possibility of a “domino effect” should be guarded against. Panel units should be stacked against both sides of the supports to equalize loading and to avoid potential 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. Undue discoloration or staining is that which standard cleaning methods cannot readily remove or that does not meet the written project requirements.

**Standard****Commentary**

For safe product storage, dunnage shall be of sufficient size and shape to minimize excessive or differential settlement.

Staggered or irregular blocking should be avoided. When setting units in direct contact, protective blocks should be placed immediately in line with the supports of the first unit.

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

Precast concrete units should be protected from contact with earth, oil, tar, or other materials that could cause permanent staining.

**2.7.4 Loading****C2.7.4 Loading**

Products to be loaded on shipping equipment shall be blocked at points that are correctly placed in accordance with the shop drawing or established plant procedures.

Blocking, packing, padding, and other protective materials shall not cause damage to the units.

Proper supports, blocking, cushioning, padded tie-down chains, and straps should be used to prevent damage.

**2.8 Surface Finishes****C2.8 Surface Finishes****2.8.1 General****C2.8.1 General**

Project requirements for all surface finishes shall be stated on the shop drawings. Finishing processes shall produce an acceptable appearance without detriment to the required concrete properties.

Specified finishes for structural concrete members should be commensurate with intended use and location within the structure. Specifying unnecessarily stringent finish requirements increases costs without improving the performance of the products.

Concrete is a variable material. Even after final finishing, there will be a range of color and texture in the surface. Some variations are to be expected.

Many finishes cannot be achieved with equal visual quality on all faces of the unit. The reason for this is due to several factors such as mix proportions, variable depths (pressure) of the concrete, casting orientation, and differences in consolidation techniques. This is particularly true for intricate shapes.

It is recommended that samples be made for special finishes on a per project basis. Plant specific special finishes should be detailed in the "Quality System Manual."

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

As-cast formed surface finishes shall be made in accordance with the project requirements.

This article refers to surface finishes that are exactly as-cast directly on the form or form liner. These finishes are typically unprocessed with no retardation, sandblasting, or acid washing. However, the use of a light sandblasting to only prepare the surface for a coating application is generally considered to be an "as-cast" finish.

**Standard****Commentary**

When required by project specifications, finish samples shall be prepared to establish acceptable limits for the appearance of form joints, form blemishes, and air voids. If color uniformity is a finish acceptance criterion, the provisions for Special Finishes of this division shall apply. For additional information on special finish requirements, refer to Article A2.8, Surface Finishes.

Even with good quality control, as-cast finished concrete will exhibit some negative aesthetic features such as color variations, air voids, minor surface crazing, and blotching. This is especially true for non-profiled flat panels. Repairs to this type of finish tend to be even more noticeable after weathering. Project specifications for as-cast surface finishes should account for such difficulties.

Formwork for smooth-surfaced concrete is often the most difficult of any type of formwork encountered for precast concrete. This is particularly true where large single-plane surface areas are involved. Even minor imperfection or misalignment in the surface of the form will be apparent in the surface finish.

Most precast structural concrete is cast in steel forms. Unless special surface treatments are specified, minor irregularities and imperfections are to be expected in the surface of the precast unit. Due to length requirements, it generally is not possible for the form manufacturer to fabricate forms from one continuous piece of steel plate. Instead, plates of various sizes are welded together with the joints ground smooth. The connection of differing side forms and end bulkheads also contributes to irregularities. The transfer of these irregularities in the steel forms to the surface of the concrete cannot be avoided, nor can the resultant blemishes be rendered invisible by remedial repair.

An impervious surface such as a plastic liner, steel, overlaid plywood, or fiberglass surfaced plywood will usually result in a lighter color and more uniform appearance. However, regardless of the forming material, joints are always difficult, if not impossible, to hide.

Vertically cast surfaces will exhibit air holes (“bugholes”). When air voids of a reasonable size are encountered on vertically cast surfaces, it may be more desirable not to fill and rub the voids as color variations can occur with this type of repair.

It may be appropriate to establish an acceptable level of air voids with respect to frequency, size, and distribution through the use of samples or mock-ups.

Smooth cement film on the surface may be susceptible to surface crazing (fine and random hairline cracks) when exposed to wetting and drying. In most cases, this is a surface phenomenon that will not affect the structural properties or durability. In some environments, crazing will be accentuated by dirt collecting in the minute cracks and will generally become more apparent in horizontal surfaces.

**Standard****Commentary****2.8.3 Exposed or Visible Unformed Surface Finishes****C2.8.3 Exposed or Visible Unformed Surface Finishes**

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 floated.

The unformed surface of a precast unit may be given a variety of finishes depending on the intended service or appearance. These may include a screed, float, trowel, light broom, or stippled finish.

Finishing operations shall be performed in such a manner that the concrete is worked and manipulated as little as possible in obtaining the desired result. Overworking of the surface shall be avoided.

Overworking of the concrete surface may bring excessive fines and water to the top, which reduces the quality of the finished surface causing such undesirable effects as checking, crazing, dusting, and discoloration.

If excess moisture or bleed water accumulates after strike-off or rough floating, it shall be removed or allowed to evaporate before the next finishing operation is performed. Under no circumstances shall neat cement, mixtures of sand and cement, or other substances be worked into the surface to dry such areas.

Overworking the surface of structural lightweight aggregate concrete should be avoided due to the tendency of the aggregate to float to the surface and create a “bumpy” texture. Magnesium floats and screeds should be used with air entrained or lightweight concrete to minimize surface rippling, tearing, and pullouts.

Adjustments to concrete mix proportions may be required if excessive moisture or bleed water appears and accumulates between finishing operations.

When final troweling is required, the surface shall be manipulated only as necessary to produce the specified finish and to close surface cracks that may have developed.

Excess bleed water may be removed by blotting with mats, draining, or pulling off with a loop of hose. Finishing operations should not proceed until accumulated water has been removed or has dried.

Prior to initial set of the concrete, an inspection shall be made to ensure that the floating or finishing operations did not result in high areas or ridges around embedments. Screeded areas shall also be inspected to ensure uniform thickness that is within the tolerance limits.

Troweling should not be done on a surface that has not been screeded or floated first.

When a special finish is required for bond to a secondary concrete casting, finishes shall be in accordance with project design requirements. Excessive loose laitance shall be removed from the surface to be bonded.

For composite finishes, rough wood floating following initial strike-off is generally considered adequate. However, scarifying the surface with a rake or wire brush may be required to meet specific design requirements.

**Standard****Commentary****2.8.4 Applied Coatings**

When concrete is to be painted or stained, mold release agents compatible with the coating shall be used. All types of release agents shall be permitted if surface preparation for the purpose of assuring adhesion between the coating and the concrete is required.

**C2.8.4 Applied Coatings**

Light sandblasting or scarifying that is performed to help ensure proper bond of applied coatings will eliminate possible detrimental effects of the mold release agent.

Paint and stains are formulated to provide certain performance characteristics under specific conditions and may be used for purely decorative reasons. See Article 2.11 for information on both clear and pigmented sealers. There is a significant difference between paint or stain types, brands, and performances. Knowledge of the service conditions is necessary for selecting an appropriate paint or stain.

Coatings applied to exterior surfaces should be impermeable to liquid water, but not water vapor. The coating manufacturer's recommendations for mixing, thinning, tinting, and application should be strictly followed.

**2.9 Repairs**

When non-compliant 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.

**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.

The techniques and materials for repairing structural precast concrete are affected by a variety of factors. Accordingly, precise methods of repair cannot be detailed in this manual.

The manufacturer's recommendations for curing repair materials shall be followed.

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 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.

Repair work requires expert craftsmanship and careful selection and mixing of materials.

Repair methods should ensure that the repaired area will conform to the balance of the work with respect to applicable requirements for appearance, structural adequacy, serviceability, and durability. Repairs should be made at the plant well in advance of shipping to allow for proper curing of the repaired area. Color variations can be expected between the repaired area and the original surface

**Standard****Commentary****2.10 Acceptability of Appearance**

Finished surfaces shall be evaluated based on comparison with established plant procedures, specific project standards, or samples.

Appearance of the surface shall not be evaluated when light is illuminating the surface from an extreme angle.

due to the different age and curing conditions of the repair. The repair will generally become less noticeable over time with exposure to the environment.

Small cracks, under 0.010 in. (0.25 mm), may not require repair. Cracking in members that are exposed to corrosive environments should be evaluated for repair by the engineer. If crack repair is required for the restoration of

structural integrity, cracks may be filled or pressure injected with a low viscosity epoxy.

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

**C2.10 Acceptability of Appearance**

Uniformity of appearance is generally a matter of subjective individual judgment. Therefore, it is beyond the scope of this Standard to establish definitive rules for product acceptability on the basis of appearance.

Angled lighting will accentuate surface irregularities due to shadowing. Surfaces should be evaluated from a reasonable viewing distance, generally not less than 20 ft (6 m).

It is recommended that all edges of precast concrete units be detailed with a radius or chamfer, as sharp corners are more susceptible to damage. It is also more difficult to cast concrete at a 45-degree or sharper angle due to aggregate size. Casting sharp angles can result in segregation and an accumulation of fine aggregate, which may result in poor consolidation or a weakening of the affected area.

Sculptured panels, channel panels, and panels with deep returns will likely have visible air voids on the returns. Refer to Article C 2.8.2, As-Cast Formed Surface Finishes, for further information on such finish appearances.

Project standards should be used to establish acceptable air void frequency, size, and distribution if anticipated to be a problem.

The surface finish of returns may not appear exactly like the front face (down-face) due to a number of factors such as mix proportions, variable depths, and consolidation techniques. This is particularly the case with intricate shapes and complex placement requirements. The effect of gravity during consolidation tends to force the large aggregate downward, which displaces small aggregate, sand, and cement paste upwards. Consequently, the down-face in the form will generally be more uniform and denser than the top-face and returns. Due to such factors, it should

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**2.11 Sealers And Clear Surface Coatings**

If sealers or clear surface coatings are specified, the precast units shall be prepared and the coatings applied in accordance with the manufacturer's recommendations.

Coatings shall not be applied to surfaces that are to be bonded to other materials, unless specifically permitted by the manufacturer or when material compatibility is verified by sample testing.

Products that are to receive a sealer shall be treated and cured in accordance with the sealer manufacturer's recommendations.

be recognized that blemishes and variations in color occur in structural precast products.

**C2.11 Sealers And Clear Surface Coatings**

Sealers are generally not required in conjunction with the high quality, low-permeability plant produced precast concrete members. Sealers are occasionally used to reduce deterioration due to freeze-thaw cycles or when deicing compounds are used. Periodic re-application of sealers will be required in such situations for maximum effectiveness.

Sealers can generally be removed by light abrasive blasting when necessary. Sealers should not be applied if surfaces are to be coated, unless the sealer is compatible with the specific coating.

# DIVISION 2 - PRODUCTION PRACTICES

## PROVISIONS FOR SPECIAL FINISHES

The following Articles, designated with an “A” prefix, apply to structural products with an architectural finish requirement. Conformance with the requirements of the Articles is required as part of certification in the Product Categories “Bridge Architectural” (BA), or “Commercial Architectural” (CA) within the Bridge Products and Commercial (Structural) Products Groups. For a description of these Groups, see Appendix F, *Certification Programs – Product Groups and Categories*.

The criteria established in this manual govern except as specifically modified by these provisions for the special class of products defined above.

The Article numbers are the same as the corresponding Articles in the main portion of the Standard. Where a special provision for architectural finishes does not have a matching Article in the main portion of the Standard, the provision is placed at the end of an Article or the Division with numbering continued sequentially.

### Standard

### Commentary

#### A2.2 Production and Curing Facilities

#### AC2.2 Production and Curing Facilities

##### A2.2.6 Curing and Finishing Areas

##### AC2.2.6 Curing and Finishing Areas

When final inspection is made for comparison to the approved samples for color and texture, lighting is extremely important. To the nearest extent possible, indoor lighting should be made similar to natural lighting.

#### A2.4 Forms

#### AC2.4 Forms

##### A2.4.1 Materials and Construction

##### AC2.4.1 Materials and Construction

Forming materials shall not warp or buckle due to temperature changes or moisture, which can cause unsightly depressions and uneven swells in the finished surface. The forming materials shall be nonabsorbent or properly sealed to prevent excessive moisture absorption. This is to minimize variations in finish. The precaster shall evaluate the effect of different forming materials used in the same forms on the color of the finished surface.

The appearance of the finished surface is directly related to the type and quality of the forming material. Forms for Category BA or CA units can be made of various materials such as plywood, concrete, steel, plastics, polyester resins reinforced with glass fibers, plaster, or a combination of materials.

Forms shall be coated with release agents that will not stain the concrete.

The selection of a release agent should include evaluation of the effect on discoloration or staining of the concrete surface. If the surface mortar is to be removed by sandblasting or other means, surface discoloration caused by the release agent generally will not affect the final finish.

**Standard****Commentary**

Assembled forms shall not allow leakage of water

Joints in the form material shall be made to minimize reflection in the concrete surface to the extent permitted by the approved samples.

The surface condition of the forms, joints, and coating materials shall be visually inspected prior to use.

Joints should be inspected daily during the form preparation stage. Form joints resulting from connecting loose parts, such as bulkheads, side, or top forms should be minimized. Forming components should be well fitted, firmly secured, and sealed to prevent leakage.

A basic assessment of the forms should be made in advance of concrete placement. The assessment should ensure that:

1. the forms have been assembled correctly within specified tolerances,
2. the release agent has been properly applied without excessive ponding, and
3. debris such as concrete splatter, wire ties, and dust have not contaminated the surface of the forms.

**A2.7 Product Handling****AC2.7 Product Handling****A2.7.2 Stripping****AC2.7.2 Stripping**

Veneered units should be lifted cleanly to prevent chipping or spalling of the veneer edges. Uniformity of stripping age from unit to unit should be maintained to minimize concrete color differences.

**A2.7.3 Yard Storage****AC2.7.3 Yard Storage**

Dunnage shall be made with a material that will not stain or damage the finished units. When necessary, storage apparatus shall be protectively covered to avoid discoloration or staining of exposed surfaces.

**A2.7.5 Cleaning****AC2.7.5 Cleaning**

All surfaces of the precast concrete units to be exposed to view shall be cleaned, as necessary, prior to shipping. The cleaning procedure shall not detrimentally affect the concrete surface.

A small area should be cleaned and appraised to be certain there is no adverse effect on the surface finish before proceeding with complete cleaning. For information on removing specific stains from concrete, refer to "Removing Stains and Cleaning Concrete Surfaces," IS 214, published by the Portland Cement Association.

**A2.8 Surface Finishes****AC2.8 Surface Finishes****A2.8.1 General****AC2.8.1 General**

Each plant shall develop quality requirements for

Finishing techniques vary considerably between

**Standard**

Category BA or CA product finishes prior to undertaking actual production. Such requirements shall include samples and production procedures.

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individual plants. Many plants have developed specific techniques supported by skilled operators or special facilities. In addition, many finishes cannot be achieved with equal visual quality on all faces of the unit. The reason for this comprises several factors such as mix proportion, variable depths, and consolidation techniques. This is particularly the case with intricate shapes and complex placement requirements.

It should be recognized that some blemishes or variations in color occur in Category BA or CA precast concrete. For example, units containing aggregate 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, variations in the depth of exposure and 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 mottled for the same reason.

Form-finished units may appear less uniform in color than the same units subsequently given an exposed aggregate finish. A buff colored finish achieved with fine aggregate is more easily controlled, even with gray cement. Uniformity in color, even within small units finished with coloring may vary from unit to unit. Color variation of precast concrete can occur due to daily variations in the water-cementitious material ratio and curing conditions for the concrete. This is less pronounced in mixes using white cement than mixes with gray or buff cement. The degree of uniformity normally improves with an increased depth of aggregate exposure.

Final orientation of the aggregate may result in differences in exposure between the down-face and returns in exposed aggregate surfaces. Emphasis should be placed on choosing suitable concrete mixes with aggregates that are reasonably spherical or cubical in shape. For large returns (deep, vertically cast sections of a unit), or situations where it is necessary to minimize variations in appearance, aggregate sources should be selected that provide uniform and preferably fully graded material. Exposures should be medium to deep and color differences between the ingredients of the mix 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 in the same orientation. If this production

**Standard****Commentary**

Reference samples or mock-up units shall be available in the plant to ensure the required finish is being met.

Aggregate exposure or “reveal” shall be no greater than one-third the average diameter of the coarse aggregate or not more than one-half the diameter of the smallest size coarse aggregate particle.

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

Appearance, color, and texture of the surface finish of all units shall match within an acceptable range of approved sample panels.

**A2.8.2 As-Cast Formed Surface Finishes**

The forms 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 distribution.

method is utilized, suitable fillets, reinforcement at the corners, and a groove or architectural feature at the dry joint should be utilized. Although the dry joint may not show with certain mixes and textures, a groove is generally required.

As a general rule, a textured surface is more aesthetically pleasing than a smooth surface. This is primarily due to the ability of texture surfaces to camouflage subtle differences in the surface finish.

**AC2.8.2 As-Cast Formed Surface Finishes**

A smooth off-the-form finish may be economical, but perhaps the most difficult to produce when a high level of color uniformity is required. The cement provides the primary color influence on a smooth finish. Sand may also influence color but is less likely to be a significant influence unless the sand contains a high percentage of fines or is highly colored. However, as the surface weathers and the sand becomes more exposed, its influence on color becomes more pronounced. The coarse aggregate should not be a significant influence on color unless a high degree of consolidation is required. This may cause some aggregate transparency resulting in a blotchy and nonuniform appearance.

Aggregate transparency or “shadowing” usually occurs in light colored, formed concrete surfaces. It is characterized by dark areas similar in size and shape of the coarse aggregate and is more pronounced on smooth surfaces.

**Standard****Commentary****A2.8.5 Sand or Abrasive Blast Finish****AC2.8.5 Sand or Abrasive Blast Finish**

Sand or abrasive blasting of surfaces is suitable for exposure of large and small aggregates. Uniformity of depth and exposure is essential for achieving an acceptable finish. Skill and experience of the operator plays a significant role in achieving a uniform finish. Consequently, the same blasting crew and equipment should be used for the duration of the project when possible.

The type and grading of abrasive affects the resulting surface finish. Differences in shading and to some extent, color will vary with the degree of aggregate exposure. The age of the unit at the time of blasting will also affect the rate of material removal and depth of aggregate exposure. The age and strength of the concrete at the time of blasting should be consistent throughout the project to help achieve the desired finish.

The degree of uniformity obtainable in a blasted finish is generally in direct proportion to the depth of removal. A light blasting may look acceptable on a small sample, but uniformity is difficult to achieve in a full-size unit. A light blast will emphasize visual defects and reveal imperfections previously hidden. The lighter the blast, the more critical the skill of the operator becomes. This is particularly true in sculptured units.

Sculptured units generally will have air voids on the returns, which may be accentuated by a light blast. Due to the difficulty of obtaining such a finish, small air voids up to 1/4 in. (6mm) should be considered acceptable as sack rubbing may cause an undesirable color variation.

Brush blasting, which is little more than a uniform scour cleaning, is used to remove minor surface variations. A brush-blast surface seldom appears uniform at close inspection. Consequently, it should be viewed at a distance for determining acceptability. This finish is normally used on features such as reveals for accentuating an area. It is also commonly used to help improve the bond of applied coatings.

“Bank” or “river” sand should not be used as a blasting abrasive.

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

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**Commentary**

**A2.8.6 Acid Etched Finish**

In cases where aggregate is to be exposed to a considerable depth, acid resistive siliceous aggregate shall be used.

The concrete unit shall be well wetted with clean water prior to acid treatment to help control the rate and depth of penetration. Acid shall not be allowed to remain on the surface longer than 15 minutes. Deep etching shall be achieved by multiple treatments. After completion of acid etching, the unit shall be thoroughly flushed with water.

**AC2.8.6 Acid Etched Finish**

Acid etching may be accomplished by: (1) brushing the surface with a stiff-bristled brush that has been immersed in the acid solution; (2) spraying acid and hot water onto the panel surface using specially designed pumps, tanks, and nozzles; or (3) immersing the unit for a maximum of 15 minutes in a tank containing 5 to 35% acid. Acid etching is most commonly used for light or medium aggregate exposure. Acid etching of concrete surfaces will result in a fine, sandy texture if the concrete mix is uniform and properly consolidated. Non-uniform concrete mixtures, aggregate color, and acid application techniques may cause appearance problems. The potential for appearance problems increases with large planar surfaces and light acid etching techniques. Carbonate aggregate, such as limestone, dolomite, and marble, may discolor or react with the acid due to high calcium content.

With light textures, the color compatibility of the cement and the aggregate is more important. White or light colors are more forgiving to the eye and increase the likelihood of a better color match between units. There is a minimum depth of etch that is required to obtain a uniform surface. To attempt a lighter texture may result in a blotchy finish. A light depth of reveal only exposes sand and the very tips of the coarse aggregate.

It is difficult to achieve a light exposure that is uniform on highly sculptured panels. This is due to the acid concentrating in areas such as inside corners. This may, however, be acceptable if the sculpturing creates differential shadowing.

Pre-wetting the concrete with water fills the pores and capillaries and prevents the acid from etching too quickly and deeply. This also helps in flushing the acid after etching. Older and dry concrete is likely to be more carbonated. Although the reactions of carbonates with the acid are not necessarily faster than with other cement compounds, it causes increased effervescence. This gives the perception of a faster rate of etching. Acid solutions lose strength quickly once in contact with cement paste or mortar. However, extended contact with even weak solutions can be harmful to the 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.

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**Commentary**

In sandwich wall panels where the insulation is exposed at the edges of the panel, only etching methods that do not damage the insulation shall be utilized.

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

Prior to acid etching, all exposed metal surfaces, particularly galvanized metal, shall be protected with acid-resistant coatings. Metal surfaces damaged by acid shall be treated with a compatible protective coating.

**A2.8.7 Retarded Finish**

Surface retarders that are used to expose the aggregate shall be properly evaluated prior to use. A sample panel shall be made to determine effects created by the form and concrete materials. This involves using the particular type of selected concrete mix.

When using a retarder, the manufacturer's recommendations shall be followed. Surface retarders shall be uniformly applied by roller, brush, or spray.

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

Galvanized metals may be repaired with a minimum 3-mil thickness of a single component zinc-rich compound with 95% pure zinc in the dried film.

**AC2.8.7 Retarded Finish**

Retardation is performed by applying a specialized chemical directly to the plastic concrete surface (normally transferred from a coating adhered to the form surface) that delays the surface cement paste from hydrating.

Chemical retarders are available for the facedown 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 appearance and uniformity normally improves with an increase 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 mix. The depth of reveal or retardation will be deeper: (1) the wetter the mix; (2) the slower the time of set; (3) the more aggregate in the mix; (4) the closer together the coarse aggregate is; and (5) with the type and concentration of the retarder.

Retarders function by delaying, not preventing, the cement hydration. This concept will help in analyzing various mix designs for depth of retardation. For example, as the sand or coarse aggregate in the mix increases there will be less cement paste per volume of material at the surface. This change in the mix proportions will result in a deeper exposure for similar retarder concentrations. It should be noted that some retarders are effective for long periods of time while others are only active

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Water shall not contact the retarder on the form surface before the concrete is placed.

The retarded surface shall be exposed by removing the cement paste to a level that matches the approved sample.

**A2.8.8 Tooled or Bush-hammered Finish**

Operators shall be trained to produce a uniformly textured surface when exposing aggregate by tooling or bush hammering.

**A2.8.9 Honed or Polished Finish**

Compressive strength of the concrete or repair material shall be a minimum of 5,000 psi (35 MPa) before starting honing or polishing operations. The concrete shall have a uniform and dense surface. When choosing aggregate, special consideration shall be given to hardness. Care shall be taken to obtain a uniform depth of grind from unit to unit to minimize finish variations. An

for a few hours.

Water activates the retarder.

The retarded cement paste should be removed the same day that the units are stripped. Delays in removing the paste will result in a lighter, less uniform etch. Preliminary tests should be performed before planning the casting for a large project to determine the most effective finishing time. The timing of surface finishing operations should be consistent from day to day.

**AC2.8.8 Tooled or Bush-hammered Finish**

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 bush hammering and is most suitable for flat or convex surfaces. Pneumatic or electric tools may be fitted with a bush hammer, comb chisel, crandall, or multiple-pointed attachments. The type of tool is determined by the desired surface effect. Hand tools may be used for small areas, corners, and for 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 the tooling produces a definite pattern on the surface. Variations due to more than one person working on the panels may occur. Care should be exercised to avoid exerting excessive pressure on the tool, so as not to remove more material than necessary.

Bush hammering at outside corners may cause jagged edges. If sharp corners are desired, bush hammering should be held back from the corner. If areas near corners are to be tooled, this should normally be done by hand. Chamfered corners are preferred with tooled surfaces. With proper expertise 1-in. (25-mm) chamfers may be tooled. It is also feasible to execute tooling along specific lines.

**AC2.8.9 Honed or Polished Finish**

The grinding of concrete surfaces produces smooth, exposed aggregate surfaces. Grinding is also called honing and polishing depending on the degree of smoothness of the finish. Generally, honed finishes are produced by using grinding tools varying from approximately No. 24 coarse grit to a finer grit of approximately No. 220. This produces a smooth matte finish free of pits and scratches. Polishing is

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approved sample unit shall be kept near the grinding operations for comparison and evaluation of the product finish. Air voids in the concrete surface shall be filled before each of the first few grinding operations or no later than halfway through the third grinding step using a sand-cement mixture that matches the paste of the concrete. Careful filling and curing are required and the next grinding operation shall not be performed until the fill material has reached sufficient strength.

accomplished after honing. Polishing consists of several successive grinding steps, each employing finer grit than the preceding steps. A buffer brick or felt pad with tin oxide polishing powder is used to produce a high gloss polish.

Form flatness should be  $\pm 3/32$  in. over 13 ft ( $\pm 2$  mm over 4 m). For a large project with many castings, it may be economically viable to have the form surface machined to a specified flatness. This will reduce the time of polishing operations. Before polishing, panels should be carefully leveled.

Uniformity of appearance generally is not a problem on flat cast faces, but vertically cast faces are likely to show variations in aggregate density.

When a 90-degree 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 more dense and uniform surface.

Care should be exercised in the application of polishing compounds to prevent creating a visually unacceptable halo effect on the surface. This is of particular concern if applied manually over a portion of the surface during the blending of imperfections.

**A2.8.10 Form Liner**

**AC2.8.10 Form Liner**

Form liner panels shall be secured in the forms by methods that will not impair the intended finish. Steps shall be taken to camouflage anomalies to within the pattern of the texture.

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

A form liner texture can be of considerable influence in assisting as-cast surfaces to appear more uniform. Form liner material selection depends on the amount of usage and whether the pattern has undercut (negative) drafts. Matching joints between liners is very difficult. Products employing liner finishes should either be limited to widths less than the available width of liner sections, or liner joints should be at form edges or be detailed as an architectural feature in the form of a groove, recess, or rib.

An investigation shall be made to determine whether staining or discoloration may occur from the liner material, fastenings, or joint sealers. Care shall be taken to use form release agents and

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retarders that are compatible with the liner material. The liner shall not be subjected to temperatures in excess of those recommended by the manufacturer.

**A2.8.11 Embedded Veneer Facing Materials**

Quality requirements for design and production procedures of finishes with embedded veneer facing materials shall be established on the basis of prior experience or test samples.

Particular attention shall be paid to the compatibility of material with respect to differential expansion and contraction caused by thermal and moisture changes. If the veneers are not compatible with the concrete, the final design shall include compensation for the differences in compatibility.

**Natural stone.** Cut stones that are easily stained by oils and rust shall be protected by lining the forms with polyethylene sheets or other non-staining materials.

A complete bond breaker between natural stone veneer and concrete shall be used. Bond breakers shall be one of the following: (1) a liquid bond breaker applied to the back surface of the veneer prior to placing the concrete; (2) a minimum of 4 mil polyethylene sheet; or (3) a 1/8 in. (3 mm) polyethylene foam pad or sheet. The bond breaker shall prevent concrete from entering the spaces between the pieces of veneer. The veneer shall be connected to the concrete with mechanical anchors that can accommodate the expected magnitude of relative movement. Preformed anchors fabricated from Type 302 or 304 stainless steel shall be used unless otherwise specified. Close supervision is required during the insertion and setting of the anchors. Anchors placed in epoxy shall not be disturbed until the epoxy has cured.

When using epoxy in anchor holes, 1/2-in. (12 mm) long compressible rubber or elastomeric grommets or sleeves shall be used on the anchor at the back surface of the stone. The epoxy

**AC2.8.11 Embedded Veneer Facing Materials**

Color control or blending for uniformity should be done by the stone plant, as the desirable characteristics are easier to see during the finishing stages. A qualified representative of the owner who understands the aesthetic appearance required 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.

Prior to awarding the contract, the owner or owner's representative should conduct testing to determine the pertinent physical properties of the veneer material. The material testing should be performed on samples with the same thickness and finish as will be used in the structure.

**Natural Stone.**

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manufacturer's recommendations for mixing and curing temperature limitations shall be followed. The strength of the stone veneer and anchorage system shall be determined to assure adequate strength for handling, transportation, erection, and service conditions.

Veneer joints within a concrete element shall allow for differential movement between materials in the form. The veneer pieces shall be temporarily spaced with a non-staining compressible gasket that will not adversely affect application of the sealant. Shore A hardness of the gasket shall be less than 20 durometer.

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

When stone veneer is used as an accent or feature strip on precast concrete panels, a 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.** Brick with an initial rate of absorption (suction) of less than 30g/30in.<sup>2</sup>/minute (30g/194cm<sup>2</sup>/minute), when tested in accordance with ASTM C67, are not required to be wetted prior to concrete placement. However, brick with suction in excess of 30g/30in.<sup>2</sup>/minute (30g/194 cm<sup>2</sup>/minute) shall be wetted prior to placement of the concrete. Terra cotta units shall be soaked in water for at least one hour prior to placement and shall be damp at the time of concrete placement.

The color of brick or tile will vary within and between lots. To minimize the effect of color variation, the brick or tile shall be randomly mixed. Clay products that have surface imperfections, such as chips, spalls, face score lines, and cracks, shall be culled in accordance with approved samples and applicable ASTM specifications.

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

Clay products with high suction should be wetted prior to placement of the concrete to reduce the amount of mix water absorbed. Unglazed quarry tile and frost-resistant glazed wall tiles generally are not required to be wetted.

Normally, the clay product supplier will preblend the brick or tile prior to shipment to the precaster. Ceramic glaze units for exterior use may develop craze cracking from freeze-thaw cycles and bonding may fail.

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Clay product faced units shall be accurately sized by use of a template or grid system. When an elastomeric form liner is used, it shall be produced to within a tolerance of  $\pm 1/32$  in. ( $\pm 0.8$  mm).

In addition to normal dimensional inspections, clay product coursing shall be re-inspected for alignment and proper seating against the form face.

Care should be taken during mortar or concrete placement and consolidation to prevent movement of the individual pieces. If required, joints between brick and tile shall be filled with pointing mortar or grout. Before pointing, joints shall be saturated with clean water.

When applying thin brick and ceramic tile to a recessed concrete surface, the surface shall be roughened or otherwise prepared in accordance with the mortar bonding requirements. Dry-set mortar shall conform to ANSI A118.1. Latex-portland cement mortar shall conform to ANSI A118.4. Installation of dry-set and latex-portland cement mortars shall conform to ANSI A108.5. Particular attention shall be directed towards the manufacturer's recommendations for curing of latex-portland cement mortar.

Units shall be grouted and tooled using dry-set or latex-portland cement grouts in accordance with the material and installation specifications contained in ANSI A118.6 and ANSI A108.10.

**A2.8.12 Sand Embedded Materials**

Care shall be taken to ensure that facing aggregate is dense and evenly distributed on all surfaces. This is particularly important around corners, edges, and openings. When facing materials are of mixed colors, placement in the form shall be inspected for the formation of unintended patterns or localization 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.

The dimensions of some bricks are too inaccurate for precast concrete applications. Individual brick tolerances of  $\pm 3/32$  in. ( $\pm 2$  mm) or greater may cause problems. Brick may be available from some suppliers with the necessary tolerances for precasting of  $\pm 1/16$  in. ( $\pm 2$  mm). Acceptable dimensions can also be obtained by saw cutting each brick, but this substantially increases cost.

After the joints are properly pointed and have become thumbprint hard, the joints should be tooled to a smooth concave surface, or struck and troweled flush with the face of the clay units. The concave surface is best for durability. Initial grout cleanup should be done within 15 minutes of pointing to avoid excessive hardening of the grout. Final cleanup should be completed within 60 to 90 minutes.

When dry-set mortar is used, the requirement of wetting the concrete surface or the clay product may be eliminated.

**AC2.8.12 Sand Embedded Materials**

The sand embedment technique reveals the facing material and produces the appearance of a mortar joint on the finished panel. Bold and 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 prior to placing concrete over the bedding. The depth of the bedding material should provide a reveal equal to 25% to 35% of the stone's diameter. To help achieve uniform distribution and exposure, all aggregate

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**A2.10 Acceptability of Appearance**

It is beyond the scope of this Standard to establish definitive rules for product acceptability on the basis of appearance. The finished face surface shall have no obvious imperfections or evidence of repair other than minimal color and texture variations. The acceptability of appearance shall be made in comparison with the approved sample in good daylight conditions. The unit and approved sample should be viewed with the unaided eye at an appropriate distance of 20 ft (6 m) or greater.

Unless approved otherwise in the sample/mock-up process (reference Article 1.5.4, Visual Mock-ups and Initial Production Approval of Finishes), the following is a list of finish defects that shall be properly repaired if readily visible when viewed at a 20-ft (6 m) distance.

1. Ragged or irregular edges.
  
2. Excessive air voids (commonly called bug holes) evident on exposed surfaces.
  
3. Adjacent, flat, or return surfaces with greater texture and/or color differences than the approved samples or mock-ups.

should be approximately one size.

**AC2.10 Acceptability of Appearance**

Uniformity of color and intensity of shading are generally a matter of subjective individual judgment.

1. Typical edge conditions should be demonstrated in the project samples. Voids may occur on 45-degree or sharper edges due to large aggregate particles. Therefore, the edge should be 45 degrees or less and have a cutoff or quirk. The size of the quirk return should not be less than 3/4 in. (20 mm), or less than 1.5 times the maximum aggregate size used in the concrete mix.
2. Sculptured panels, channel panels, and panels with deep returns may have visible air voids on the returns. The air voids (bug/blow holes) become accentuated when the surface is smooth, acid-etched or lightly sandblasted. If the air holes are of a reasonable size, 1/8 to 1/4 in. (3 to 6 mm), repair is not recommended. Filling and sack rubbing could be used to eliminate the voids. However, this procedure is costly and may cause color differences. Samples or the mock-up panel should be used to establish acceptable air void frequency, size, and distribution.
3. Returns in some finishes will not appear exactly like the front face (down-face) due to a number of factors such as mix proportions, variable depths, and consolidation techniques. This is particularly the case with intricate shapes and complex placement requirements. The effect of gravity during consolidation tends to force the large aggregate downward and the smaller aggregate, sand and cement paste, upwards. Consequently, the down-face in the form will generally be more uniform and denser than the returns.

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4. Casting and/or aggregate segregation lines evident from different concrete placement lifts and consolidation.
5. Visible form joints or irregular surfaces in excess of, or larger than, those accepted in the approved samples or mock-ups.
6. Rust stains on exposed surfaces.

7. Excessive variation of texture and/or color within the individual unit or adjacent units.

8. Blocking stains evident on the exposed surface.

6. Rust stains caused by reactive iron pyrites or other contaminants will occur where such contaminants are found as part of the aggregate. 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 operations. The 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 variation in color occur in precast concrete panels. Uniformity in color is primarily related to the characteristics of the ingredients supplying the color.

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

Color uniformity is difficult to achieve on gray, buff, and pigmented concrete surfaces. The use of white cement will usually provide better color uniformity than gray cement. Typical color variation in gray cement is sufficient to cause noticeable color differences in precast concrete panels. As a general rule, a textured surface provides a better aesthetic finish than a smooth surface. Over time, sunlight and exposure to the elements may even out the variation to a great extent.

8. Blocking used to separate production units in the storage yard or during shipment should be made with non-staining materials. 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 for extended periods, unless in an area that is not visible in the final structure.

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9. Areas where the backup concrete penetrated through the facing concrete.
10. Foreign materials embedded in the face of the unit.
11. Visible repairs at 20 ft. (6 m) or greater viewing distance.
12. Reinforcement shadow lines.
13. Cracks visible at a 20-ft. (6 m) or greater viewing distance.

12. Reinforcing steel shadow lines are generally evident directly over the steel.
13. It should be recognized that a certain amount of crazing or cracking might occur without being detrimental. The acceptability of cracks should be determined with respect to actual service condition requirements, structural significance, as well as aesthetics.

**A2.11 Sealers and Clear Surface Coatings****AC2.11 Sealers and Clear Surface Coatings**

If sealers or clear surface coatings are specified for architectural surfaces, testing shall be performed on reasonable size samples of varying age. The performance shall be monitored over a suitable period of time and under representative exposure conditions. Prior experience that demonstrated acceptable performance under similar exposure conditions may substitute for testing. Clear sealers shall be guaranteed by the supplier or applicator not to stain, soil, darken, or discolor the finish. The clear sealer should 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 material shall be pretested.

Sealers or clear surface coatings may be considered for the possible improvement of weathering characteristics. The quality of concrete normally specified for Category BA or CA products, even with minimum practical thickness, does not require sealers for waterproofing in most applications.

# DIVISION 3 – RAW MATERIALS AND ACCESSORIES

## Standard

## Commentary

### 3.1 Concrete Materials

### 3.1 Concrete Materials

#### 3.1.1 General

Frequent inspections shall be performed to check and evaluate test results and the finished product to identify changes that may adversely affect the properties of the concrete mix.

#### C3.1.1 General

#### 3.1.2 Cement

The type and kind of cement shall be selected to provide predictable strength and durability. Cement shall conform to ASTM C150. Concrete mixes using cement conforming to ASTM C595, C845 or C1157 shall be tested and evaluated for the intended applications.

#### C3.1.2 Cement

Unless specified, the producer should have the choice of the type and kind of cement to use for achieving the specified physical properties.

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. The producer shall maintain the test reports on file.

#### 3.1.3 Fine Aggregate

Fine aggregate for concrete mixes, other than lightweight aggregate, shall consist of high quality natural sand or sand manufactured from coarse aggregate. The fine aggregate shall comply with ASTM C33 or applicable specified requirements. Variations in fineness modulus of fine aggregate shall not exceed  $\pm 0.20$  from the value used for the mix design. Additionally, the amount retained on any two consecutive sieves shall not change by more than 10% by weight of the total fine aggregate sample.

#### C3.1.3 Fine Aggregate

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

Fine aggregate shall be obtained from sources in which representative samples have been tested in accordance with the governing specifications. Acceptable concrete-making properties of the aggregate shall have been demonstrated by trial mixes.

#### 3.1.4 Coarse Aggregate

Coarse aggregate for concrete mixes, other than lightweight mixes, shall conform to the requirements of ASTM C33.

#### C3.1.4 Coarse Aggregate

Coarse aggregate may be selected on the basis of the desired material properties, cost, or availability provided the required level of strength, durability, finishability, and workability of the mix are met.

The maximum size of coarse aggregate shall not exceed:

1. One-third of the minimum section thickness.

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2. Three-fourths of the minimum clear depth of cover.
3. Two-thirds of the spacing between individual reinforcing bars, bundles of bars, pretensioning tendons, or post-tensioning ducts.

Coarse aggregate shall be obtained from sources in which representative samples have been tested in accordance with the governing specifications. Acceptable concrete-making properties shall have been demonstrated by trial mixes.

**3.1.5 Aggregates for Lightweight Concrete**

Lightweight aggregate shall conform to the requirements of ASTM C330. Provisions for testing shall be as stipulated in Articles 6.2.2 and 6.2.3 of this manual except for testing of gradation, unit weight, and impurities. These tests shall be performed in accordance with the requirements of ASTM C330.

**3.1.6 Mixing Water**

Water, either potable or non-potable, shall be free from injurious amounts of substances that may be deleterious to the performance or quality of the concrete and steel.

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

**C3.1.5 Aggregates for Lightweight Concrete**

Producers using lightweight aggregate should be experienced in mixing and placing lightweight concrete. The effects of the aggregate weight and shrinkage characteristics often require special attention to ensure a reasonably uniform exposed aggregate finish is obtained.

Lightweight aggregate generally has a high absorption rate. If the aggregate is not saturated, it will absorb water from the mix, potentially causing a rapid slump loss. The ACI Committee 213 report titled, "*Guide for Structural Lightweight Aggregate Concrete*," provides a thorough discussion of lightweight aggregate properties, including proportioning and mixing practices.

**C3.1.6 Mixing Water**

Excessive impurities may cause efflorescence, staining, increased volume change, and reduce durability. Accordingly, limits should be set on deleterious substances contained in the mix water. Some impurities have little effect on strength and setting time; however, can adversely affect durability and other properties. In particular, the chloride ion content should be limited to a level well below the recommended maximum, when practical. Chloride ions contained in the aggregate and in admixtures should be considered in evaluating the acceptability of the total chloride ion content of mix water.

Table C3.1.6 identifies some of the more common substances and concentration limits that are known to be deleterious to concrete. Also provided in Table C3.1.6 are associated ASTM test methods for identifying and quantifying such substances. Other recognized methods such as the Environmental Protection Agency (EPA) test methods may be used when applicable.

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**Table C3.1.6 Chemical Limits for Non-Potable Mixing Water**

Substances	Maximum Concentration ppm	ASTM Method <sup>a</sup>
Soluble carbon dioxide	600	D513
Calcium plus Magnesium Chloride, as Cl <sup>-</sup>	400	D511
Iron	500	D512
Phosphate	20	b
Boron & borates	100	D4327
Alkalies (Na <sub>2</sub> O+0.658K <sub>2</sub> O)	100	D3082
Silt or suspended particles	600	D4191
pH	2000	D4192
Dissolved solids	6.0 to 8.0	b
Sugars and oils	2000	D1067
	Not detectable	b
a Other methods such as EPA or those used by water testing companies are generally acceptable b No ASTM method available.		

**3.1.7 Admixtures**

If a satisfactory history of admixture performance with specific concrete materials is not available, a trial mixture program with the concrete materials, particularly the cement, shall be conducted. The trial mixture program shall demonstrate satisfactory performance of the admixture relative to slump, workability, air content, finishability, and strength. Variations in temperature and humidity that may affect the admixture performance shall be addressed in the trial mixture program. Admixtures shall be carefully checked for compatibility with the cement or other admixtures. Effects of variations in the dosage rate and the sequence of charging the admixtures into the mixer shall be determined from the recommendations of the admixture supplier or by trial mixes.

**C3.1.7 Admixtures**

Admixtures should be materials of standard manufacturing that have established records of tests to confirm acceptable properties and performance. Expected performance of a given brand, class, or type of admixture may be obtained from one or more of the following sources:

1. Results from jobs, which have used the admixture under good technical control, and preferably using the same materials, under similar service conditions.
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 material ratio (w/cm) should be that required for the specified design strength and durability requirements of the job. Trial mixtures also can be made with a range of cement contents, w/cm, slumps, or other properties to bracket the project requirements. In this manner, the optimum mixture proportions can be selected for achieving the required results.

Admixture performance will vary due to differences in dosage rates; cement composition and fineness; cement content; aggregate size and gradation; interaction with other admixtures; sequencing; changes in w/cm; and variations in weather conditions.

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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. High-range water-reducing admixtures (HRWR), also referred to as superplasticizers, shall conform to the requirements of ASTM C494, Type F or G, or ASTM C1017, Type 1 or 2, for flowing concrete. Calcium chloride or admixtures containing chloride ions (Cl<sup>-</sup>), other than impurities from the admixture ingredients, shall not be used in prestressed concrete. This is to ensure against the development of deleterious concentrations of chloride ions in the mixing water that may cause corrosion.

Mineral admixtures or pozzolans meeting ASTM C618 or C1240 may be added for additional workability, increased strength, reduced permeability, and reduced efflorescence. If an HRWR is used with silica fume, the admixture shall be compatible with any admixture that may be contained in the silica fume. The amount of silica fume or metakaolin used in concrete shall not

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

Water reducing admixtures can be used in a variety of ways to potentially enhance the characteristics and performance of concrete. The following are several such examples:

1. A reduction in the water content while maintaining the same level of consistency.
2. Increasing the workability without increasing the water content.
3. Increasing or maintaining strength while maintaining or lowering the cementitious material content, respectively.

The reduction in w/cm achieved by reducing the mix water may produce a greater strength improvement than a similar reduction in the w/cm obtained by adding cement.

There are a variety of water-reducing admixtures classified by the amount of potential water reduction that the admixture can facilitate at a given dosage rate. The general effect of any type of water-reducing admixture on hardened concrete is increased compressive strength and a reduction in permeability. The degree to which this is achieved is primarily dependent on the amount of water reduction facilitated by the admixture.

Retarding admixtures are used primarily to offset the accelerating effect of high temperature on the set characteristics of the concrete. This is frequently used to help maintain concrete plasticity between succeeding lifts to avoid the development of cold joints or discontinuities in the unit.

High-range water-reducing admixtures can be used to increase slump without adding more water, or reduce water content without a corresponding loss in slump. Concrete mixes containing these admixtures, particularly those with initial slumps less than 3 to 4 in. (75 to 100 mm) and low w/cm, tend to lose slump and stiffen rapidly. Some high-range water-reducers combined with a retarder maintain slump for an extended period.

When a particularly smooth surface is desired, the addition of fine minerals or pozzolans conforming to ASTM C618 may be desirable. These materials also may be added to improve workability, durability, or to reduce the possibility of efflorescence. The use of fly ash or silica fume (microsilica) in a concrete mixture will darken the concrete color. The color of silica fume

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exceed 10% by weight of the portland cement unless it is demonstrated that the concrete will satisfy strength, durability, and volume stability requirements.

depends on carbon content and several other variables. Silica fume from one source may be nearly white in color, while from another, may be black. Metakaolin is a white, dry powder and does not darken white or gray concrete.

**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:

Grades of reinforcing steel required for a specific application are determined by the structural design of the precast/prestressed concrete units. All bars should be identified with mill marks as shown in Figure C3.2.1.

Billet-Steel Deformed Bars	ASTM A615/A615M
Low Alloy Steel Deformed Bars	ASTM A706/A706M
Rail-Steel Deformed Bars	ASTM A616/A616M
Axle-Steel Deformed Bars	ASTM A617/A617M

Many mills only mark and supply bars with the metric designation, which is a soft conversion. Soft conversion means that the metric bars have exactly the same dimensions and properties as the equivalent inch-pound designation as shown in Table C3.2.1.

**Table C3.2.1 English to Metric Conversion**

<b>Inch-Pound Bar Size</b>	<b>Diameter (in.)</b>	<b>Metric Bar Size</b>	<b>Diameter (mm)</b>
#3	0.375	#10	9.5
#4	0.500	#13	12.7
#5	0.625	#16	15.9
#6	0.750	#19	19.1
#7	0.875	#22	22.2
#8	1.000	#25	25.4
#9	1.128	#29	28.7
#10	1.270	#32	32.3
#11	1.410	#36	35.8
#14	1.693	#43	43.0
#18	2.257	#57	57.3

It shall be permissible to substitute a metric size bar of Grade 300 for the corresponding inch-pound size bar of Grade 40; a metric bar of Grade 420 for the corresponding inch-pound size bar of Grade 60; and a metric size bar of Grade 520 for the corresponding inch-pound size bar of Grade 75.

Sizing of reinforcing bars is often governed by dimensional limitations and the required concrete cover, in addition to the structural 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 that are closely spaced will decrease the size of potential cracks and improve the distribution of temperature stresses. This is of even more significance in thin concrete sections where the appearance and overall effect of cracking are of greater concern.

Zinc-coated (galvanized) reinforcement shall conform to ASTM A767/A767M and be chromate treated.

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

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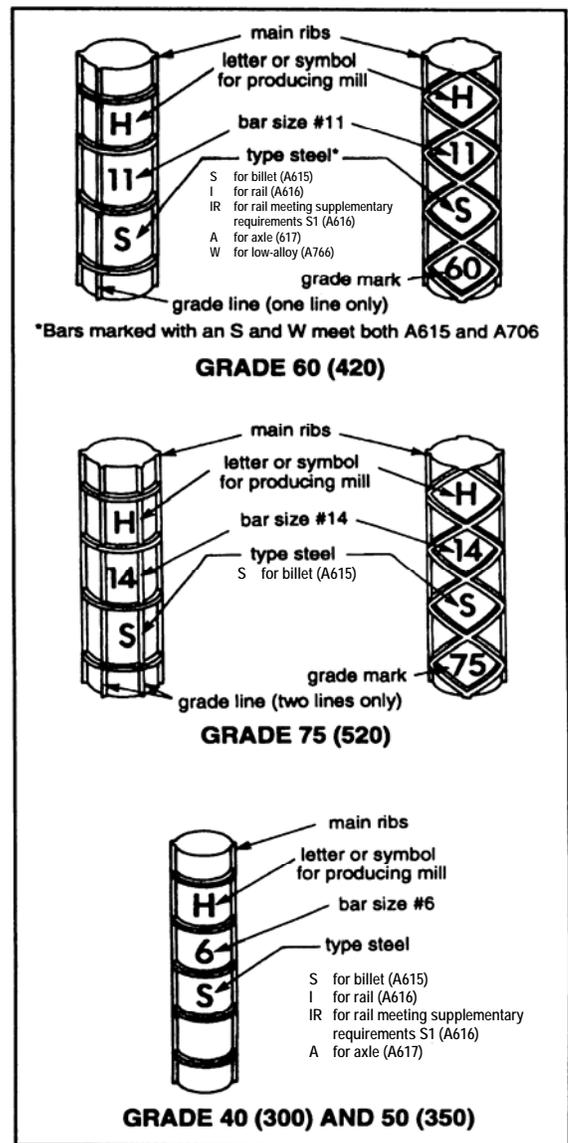
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Epoxy-coated reinforcement shall conform to ASTM A775/A775M or A934/A934M. Plants supplying epoxy-coated reinforcement shall participate in the CRSI Voluntary Certification Program for Fusion-Bonded Epoxy Coating Applicator Plants. Fading of the epoxy coating color shall not be cause for rejection of epoxy-coated reinforcing bars.

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> [610g/m<sup>2</sup>]) is normally specified for precast concrete units.

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 the cause for rejection of the coated bars.

Fig. C3.2.1 Identification Mill Marks



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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, the required properties shall be shown on the production drawings. In addition to the ASTM specification requirements, all reinforcing bars shall meet the requirements of ACI 318.

The weldability of reinforcing bars other than ASTM A706/A706M shall be evaluated according to the provisions of AWS D1.4.

Welded wire reinforcement shall conform to the following applicable specifications:

Plain Wire	ASTM A82
Deformed Wire	ASTM A496
Welded Plain Wire Reinforcement	ASTM A185
Welded Deformed Wire Reinforcement	ASTM A497

Galvanized welded wire reinforcement shall be made from zinc-coated (galvanized) carbon steel wire conforming to ASTM A641; or hot-dipped galvanized and chromate treated; or be allowed to weather.

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 coating.

Welded wire reinforcement wire spacing and sizes (gages) 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 meet the applicable ASTM specification requirements.

Plastic supports for reinforcement shall be composed of polyethylene, styrene co-polymer rubber-resin blends, polyvinyl chlorides Types I and II, or polytetrafluoroethylene. Plastic supports shall be alkali resistant and have thermal properties compatible with concrete.

Chemical analyses are not ordinarily meaningful for rail-steel (ASTM A617/A617M) and axle-steel (ASTM A616/A616M) reinforcing bars. Welding of these bars is not recommended.

Welded wire reinforcement may be used as the main reinforcement with supplemental reinforcing bars added in locations necessary to provide the required area of steel. It is recommended that welded wire reinforcement be purchased in large sheets rather than rolls to provide for better control of flatness.

**Standard****Commentary****3.2.2 Prestressing Materials****C3.2.2 Prestressing Materials**

Strand materials for prestressing shall consist of:

1. Pretensioning
  - a. uncoated, low relaxation wire strand conforming to ASTM A416, Grade 250 (1725) or Grade 270 (1860)
  - b. uncoated, stress-relieved (normal relaxation) strand conforming to ASTM A416, Grade 250 (1725) or Grade 270 (1860)
  - c. coated, low-relaxation strand, conforming to ASTM A882, 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 in multiple parallel wire tendons
  - c. high-strength, stress-relieved bars conforming to ASTM A722
  - 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.

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 non-metallic pad.

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 wedges at loads less than 95% of ultimate strength. Steel casings for strand vises shall be verified by the manufacturer as being capable of holding at least 100% of the ultimate strength of the strand.

Tendon anchorages for post-tensioning shall meet the following requirements:

Due to the significance of developing a good bond between the concrete and prestressing strand, bars, or wires, the surface condition of this material is critical. The presence of light rust on a strand has proven to enhance bond. 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," (Sason, Augusto S., PCI Journal, May-June 1992, V.37, No. 3 pp. 25-30) is cause for rejection. Pitting greatly reduces the capacity of the strand to withstand repeated or fatigue loading. It has been shown that a heavily rusted strand with relatively large pits may still obtain strengths greater than the specified requirements. However, it will not meet the fatigue test requirements.

Strand chuck maintenance should be performed in accordance with guidelines of Article 5.3.5 and Appendix D.

Post-tensioning tendons subject to exposure or condensation, and which are not to be grouted, should be

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1. Anchorages for bonded tendons tested in an unbonded state shall develop 95% of the actual ultimate strength of the prestressing steel, without exceeding the anticipated set. Anchorages which develop less than 100% of the minimum specified ultimate strength shall be used only when 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 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. The amount of permanent deformation shall be limited to a level that will not decrease the expected ultimate strength of the assembly.
3. The minimum elongation of unbonded strand in an anchorage assembly, during the test load, shall not be less than 2% when measured in a gauge length of 10 ft. (3 m).

permanently protected against corrosion by plastic coating or other approved means.

3. Elongation based on tests with a gauge length less than 10 ft. (3m) should not be cause for rejection.

Anchorage castings shall be non-porous 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 a notch or pinching effect.

Anchorages of any type may be used provided the basic requirements noted herein are demonstrated by an acceptable test program.

Sheathing for bonded post-tensioned tendons shall be strong enough to retain 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 a single wire, bar, or strand tendon. 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

Different requirements are imposed upon sheathings for bonded and unbonded tendons. In unbonded tendons, the sheathing does not transmit bond stresses from the prestressing steel to the concrete. Therefore, the sheathing must provide 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. Accordingly, the sheathing 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 may also be formed with inflatable and

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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.

removable tubes. The tendon is subsequently pulled through and no additional sheathing is required.

Grout shall consist of a mixture of cement and water unless the gross inside cross-sectional area of the sheath exceeds four times the tendon cross-sectional area. In such cases, a 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. Approved shrinkage-compensating material, which is well dispersed in the other admixtures, may be used to obtain 5 to 10% unrestrained expansion of the grout. Admixtures containing more than trace amounts of chlorides, fluorides, zinc, or nitrates shall not be used. Fine aggregate, if used, shall conform to ASTM C404, Size No. 2, except that all material shall pass the No. 16 sieve. The 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. The grout shall have a consistency that will facilitate proper placement. Water content shall be the minimum necessary for proper placement, and the w/cm shall not exceed 0.45 by weight.

Sheathing for unbonded tendons (monostrand post-tensioning system) shall be polypropylene, high-density polyethylene, or other plastics which are not reactive with the 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 non-corrosive 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. Minimum weight of coating material on the prestressing strand shall not be less

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

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than 2.5 lbs (1.1 kg) of coating material per 100 ft (30.5 m) of 0.5 in. (12.7 mm) diameter strand, or 3.0 lbs (1.4 kg) of coating material per 100 ft (30.5 m) of 0.6 in. (15.2 mm) diameter 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 cracking at the lowest anticipated temperature and shall not flow out from the sheath at the maximum anticipated temperature. Coatings shall be chemically stable and non-reactive with the tendon, concrete, or sheath.

strand.

**3.2.3 Hardware and Miscellaneous Materials**

**C3.2.3 Hardware and Miscellaneous Materials**

All hardware, connection items, inserts, lifting devices, or other apparatus shall be clearly detailed in the project documents showing size and yield strength for architect/engineer approval.

Hardware shall be made from materials that are ductile. Plates and angles shall be low carbon (mild) steel. The steel for anchors shall be of a grade and strength similar to the hardware material in which it anchors, to minimize potential welding complications. Brittle materials, such as low shock resistant, high carbon steels or gray iron castings, shall not be used. Malleable cast iron is, however, satisfactory.

Precautions should be taken to ensure that hardware elements to be welded together are compatible.

Materials used in ferrous items that are to be embedded in the concrete connecting precast elements, attaching to adjacent materials, or attaching equipment, shall conform to the requirements of the following specifications:

**Structural Steel**—ASTM A36/A36M (for carbon steel connection assemblies) except that silicon (Si) content shall be in the range of 0 to 0.04% or 0.15 to 0.20%. Phosphorus (P) content shall be in the range of 0 to 0.02% for materials to be galvanized. Steel with chemistry conforming to the formula,  $Si + 2.5P \leq 0.09$ , is also acceptable.

**Stainless Steel** – ASTM A666, Type 300 series, Grades A or B, (stainless steel anchors for use when resistance to staining merits extra cost).

**Carbon Steel Plate** – ASTM A283/A283M, Grades A, B, C, or D.

**Malleable Iron Castings** – ASTM A47/A47M, Grades 32510 or 35028.

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**Carbon Steel Castings** – ASTM A27/A27M, Grade 60-30 (for cast steel clamps).

**Anchor Bolts** – ASTM A307 (carbon steel) or A325/A325M (high strength steel for low-carbon steel bolts, nuts, and washers).

**Carbon Steel Bars** – ASTM A675/A675M, Grade 65 (for completely encased anchors).

**Carbon Steel Structural Tubing** – ASTM A500, Grade B (for rounds and shapes).

**High-strength Low-alloy Structural Steel** – ASTM A572/A572M except that silicon (Si) content shall be in the range of 0 to 0.04% or 0.15 to 0.20%. The phosphorus (P) content shall be in the range of 0 to 0.20% for materials to be galvanized. 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 for low carbon steel or ASTM A276/A493 for stainless steel with the mechanical property requirements shown in Table 3.2.3.

**Table 3.2.3 Minimum Mechanical Property Requirements for Studs**

Physical Property	Type-A AWS D1.1	Type-A AWS D1.1	Type-C ASTM A-496 (deformed bars - all sizes)	Stainless Steel ASTM A276, A496, AWS D1.6
Tensile, psi (Mpa)	55,000 (380)			
Yield, psi (Mpa) (0.2% offset)	—	50,000 (345)	—	30,000 (207)
(0.5% off-set)	—	—	70,000 (485)	—
Elongation (% in 2 in.)	17	20	—	30
Reduction of 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 non-corrosive materials. Hardware shall be properly cleaned prior to application of protective treatment.

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 of a corrosive environment. Corrosion can 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.

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Corrosion protection, when required, shall consist of one of the following:

1. Shop primer paint – FS-TT-P-645 or 664, or SSPC Paint 25.
2. Zinc-rich paint (95 percent pure zinc in dried film) – FS-TT-P-641, Type III, or DOD-P-21035, self-curing, one component, sacrificial organic coating or SSPC-Paint 20.
3. Zinc metalizing or plating – ASTM B633.
4. Cadmium plating – ASTM B766 (particularly appropriate for the threaded fasteners).
5. Hot dip galvanizing – ASTM A123 or A153.

Protective coatings should be applied in a manner to ensure against embrittlement. Additionally, loss of connection strength or reinforcement bond should not occur unless otherwise anticipated and allowed for in the design. Often, final finishing of the product 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.

4. 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. This process is particularly effective for threaded fasteners.
5. Special care should be taken when galvanized assemblies are used. Parts of connection components are often fabricated using cold rolled steel or cold working techniques, such as bending of anchor bars. 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 for 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 used for galvanizing.

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



**Standard****Commentary**

The materials of a connection shall be selected and jointed in a manner such that embrittlement of any part of the assembled connection will not occur. Non-ferrous 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, adjoining materials shall be selected that ensure the corrosion resistance is not reduced. 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.

**3.2.4 Handling and Lifting Devices**

Lifting devices shall be fabricated from ductile material. Reinforcing bars shall not be used. If smooth bars are required for lifting, ASTM A36 steel of a known grade and that are bent to the correct size shall be used. Each bar size and configuration shall be tested 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 a lifting operation. Connection hardware shall not be used for lifting or handling, unless 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 to ensure even distribution of load between loops.

Shop drawings shall clearly define insert dimensions and locations 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 the required positions utilized during the course of manufacturing, storage, delivery, and

Non-ferrous metals embedded in concrete may corrode in two ways:

1. 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.

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 expansion that may lead to increased porosity of the surrounding concrete as well as cracking and/or spalling.

A wood sealer should be applied to prevent moisture migration from the concrete to the wood. The high volume change of lumber, which occurs with changes in atmospheric humidity, may lead to cracking of the concrete. In addition, the embedment of lumber in concrete may result in leaching of the wood resins by the calcium hydroxide of the concrete. This can provide deterioration of the wood.

**C3.2.4 Handling and Lifting Devices**

The most common types of lifting devices are prestressing strand or cable loops that project from the concrete, coil 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 re-rolled rail steel with little ductility and low impact strength, especially at cold temperatures. Therefore, sudden impact loads, such as those encountered during stripping and handling may cause failure.

**Standard**

**Commentary**

erection. The establishment of safe load limits for lifting inserts or devices shall be established by full-scale testing to failure that is performed by a licensed professional engineer. For proprietary devices, the manufacturer’s recommendations for safe load limits are acceptable. Information shall also be supplied by the manufacturer on the use and installation of the devices to ensure proper performance.

**3.2.5 Strand Restraining Devices**

Devices used to deflect the strand to the required position shall be designed to minimize friction to the level consistent with the tolerances for strand tensioning. The strand shall be able to move freely over, under, or through such devices.

**3.3 Insulation**

Insulation shall conform to the following applicable ASTM standard(s):

**Expanded Polystyrene**

ASTM C578 – Type II, VIII, IX, XI

**Extruded Polystyrene**

ASTM C578 – Type IV, V, VI, VII, X

**Polyurethane**

ASTM C591 – Type 1, 2, 3

**Polyisocyanurate**

ASTM C591 – Type 1, 2, 3

**Phenolic**

ASTM C1126 – Type I, II, III

All relevant information on properties of insulating materials shall be kept on file at the plant. Care shall be exercised when the insulation is exposed to temperatures greater than 140°F (60°C).

**3.2.5 Strand Restraining Devices**

Harped strands must be held in position by devices capable of supporting the load imparted by the tensioned strand without excessive deformation. Excessive friction in such devices can cause the strand tension to vary over the length of the bed. If a strand becomes “pinched” or otherwise caught in the device, strand breakage can occur.

Strand restraining devices should be designed for an appropriate factor of safety.

**C3.3 Insulation**

Cellular (rigid) insulation used in the manufacturing of sandwich panels comes in two primary forms, thermoplastic and thermosetting. The thermoplastic insulations are known as molded expanded polystyrene (beadboard) and extruded polystyrene (extruded board). Thermosetting insulations are made of polyurethane, polyisocyanurate, and phenolic.

Cellular insulation is generally used for sandwich-type panels as it provides the particular material properties necessary for the independent layer construction. These properties include adequate compressive and flexural strength; relatively high dimensional stability; low thermal and vapor transmission; low absorption; and a low coefficient of thermal expansion.

Because the insulation is generally placed in direct contact with the plastic concrete, excessive dewatering of the fresh concrete may occur with the use of highly absorbent insulation. This will 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 molded polystyrene are highly absorbent.

**Standard**

**Commentary**

**3.4 Welding Electrodes**

**C3.4 Welding Electrodes**

Electrodes for shielded metal arc welding (SMAW) shall conform to the requirements of AWS D1.1, Section 5 or AWS D1.4, Section 5 (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).

**Table 3.4.1 Filler Metal Requirements**

Base Metal	Electrode Classifications for Welding Processes	
	Shielded Metal-Arc Low Hydrogen Electrodes	Flux-Cored Arc
ASTM A615 Grade 40 (300) ASTM A617 Grade 50 (300)	AWS A5.1 or A5.5 E70XX*	AWS A5.20 E7XT-X (Except -2, -3, -10, -GS)
ASTM A616 Grade 50 (350) ASTM A706 Grade 60 (420)	AWS A5.5 E80XX-X	AWS A5.29 EBXTX-X
ASTM A615 Grade 60 (420) ASTM A616 Grade 60 (420) ASTM A617 Grade 60 (420)	AWS A5.5 E90XX-X	AWS A5.29 E9XTX-X
ASTM A615 Grade 75 (520)	AWS A5.5 E100XX-X	AWS A5.29 E9XTX-X
ASTM A36 ASTM A500 Grade A Grade B	AWS A5.1 or A5.5 E60XX E70XX E70XX-X	AWS A5.20 E6XT-X E7XT-X (Except -2, -3, -10, -GS)
ASTM A441 ASTM A572 Grade 42 Grade 50	AWS A5.1 or A5.5 E7015, E7016 E7018, E7028 E7015-X, E7016-X E7018-X	AWS A5.20 E7XT-X (Except -2, -3, -10, -GS)
ASTM A572 Grade 60 Grade 65	AWS A5.5 E8015-X, E8016-X E8018-X	AWS A5.29 E8XTX-X

\*XX = 15 or 16

The electrodes and the shielding for gas metal arc welding (GMAW) or 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 A5.18 or AWS A5.20.

Electrodes for welding lap splices in reinforcing bars, 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:

The tensile capacity of lap welds is determined by the length and size of the welds, not by compatibility of material tensile strength. However, the chemical composition of the materials should be compatible.

## Standard

## Commentary

1. The electrodes and shielding for gas metal arc welding used to produce weld metal with a minimum yield strength of 60 ksi (415 MPa) shall conform to the latest edition of ANSI/AWS A5.28, "*Specification for Low Alloy Steel Filler Metals for Gas Shielded Arc Welding.*"
2. The electrodes and shielding gas for flux-cored arc welding used to produce weld metal with a minimum yield strength of 60 ksi (415 MPa) shall conform to AWS A5.29.
3. The plant shall maintain on file the electrode manufacturer's certification of compliance for 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 a weldable grade having a dew point of -40°F (-40°C) or lower. The plant shall maintain on file the gas manufacturer's certification that the gas mixture will meet the dew point requirement.

All low hydrogen electrodes conforming to AWS A5.1 shall be purchased in hermetically-sealed containers or shall be dried for at least two hours at a temperature between 500°F (260°C) and 800°F (430°C) before use. All low hydrogen electrodes conforming to AWS A5.5 shall be purchased in hermetically sealed containers or shall be dried for at least 1 hour at a temperature between 700°F (370°C) and 800°F (430°C) before they are used.

Electrodes shall be dried or protected from moisture in accordance with the manufacturer's recommendations. Drying of electrodes shall only be permitted one time. Electrodes that have been wet shall not be used.

When joining different grades of steel, the electrode shall be selected to match the lower strength steel. When 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).

Martensitic stainless steels that are to be post-heated (annealed, stress relieved, or used under high temperature conditions) shall be welded with straight-chromium stainless steel electrodes of the E400 series. If post-heating is not used, the welding shall be

Low hydrogen and stainless steel shielded metal arc electrode coverings should be protected from moisture. Normally, electrodes packaged in hermetically-sealed containers can be stored for several months without concern. However, after the container is opened, the coating begins to absorb moisture. Depending on the ambient air condition, the rods may need drying; 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 the air tight container. Although they must not get wet, the coating of other rods (60-11) will be damaged if heated.

**Standard****Commentary**

with austenitic chromium-nickel electrodes of the E300 series.

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. (6.4 mm) for root passes of fillet welds made in the flat position and groove welds made in the flat position with backing and a root opening of 1/4 in. (6.4 mm) or greater.
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.

# DIVISION 3 - RAW MATERIALS AND ACCESSORIES

## PROVISIONS FOR SPECIAL FINISHES

The following Articles, designated with an “A” prefix, apply to structural products with an architectural finish requirement. Conformance with the requirements of the Articles is required as part of certification in the Product Categories “Bridge Architectural” (BA), or “Commercial Architectural” (CA) within the Bridge Products and Commercial (Structural) Products Groups. For a description of these Groups, see Appendix F, *Certification Programs – Product Groups and Categories*.

The criteria established in this manual govern except as specifically modified by these provisions for the special class of products defined above.

The Article numbers are the same as the corresponding Articles in the main portion of the Standard. Where a special provision for architectural finishes does not have a matching Article in the main portion of the Standard, the provision is placed at the end of an Article or the Division with numbering continued sequentially.

### Standard

### Commentary

#### A3.1 Concrete Material

#### AC3.1 Concrete Material

##### A3.1.1 General

##### AC3.1.1 General

Frequent inspections shall be performed to check for changes in materials or proportions that may affect the surface appearance.

A change in aggregate proportions, color, or gradation will affect the uniformity of the finish, particularly where the aggregate is exposed. In smooth concrete finishes, the color of the cement (plus pigment) is the dominant factor in the color of the concrete surface. If the concrete surface is progressively removed by sandblasting, retarders, or other means, the color will be increasingly influenced by exposure of the fine and coarse aggregate.

##### A3.1.2 Cement

##### AC3.1.2 Cement

Cements shall be selected to provide the proper color in addition to other required characteristics.

Different cements have different color and strength development characteristics that can affect the desired concrete characteristics and finish. Copies of the cement strength uniformity tests, conducted in accordance with ASTM C917, should be requested from the cement supplier.

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

To minimize color variation of exposed surfaces, cement of the same type, brand, and color obtained from the same mill shall be used throughout a given project. This shall also be the same cement used in substantiating the concrete mix proportions.

Normal production variables such as changes in water content, curing cycles, temperature, humidity, and exposure to the environment tend to cause color variation. Color variation in gray cement is generally greater and more noticeable than with white cement. A more uniform gray color may be produced by using white cement with a black pigment, or a blend of white and gray cement.

**Standard****Commentary****A3.1.3 Fine Aggregate****A3.1.4 Coarse Aggregate**

Deviation from the aggregate gradation requirements of ASTM C33, to achieve a desired surface texture, is permissible.

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

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

**AC3.1.3 Fine Aggregate**

Fine aggregate can have a major effect on the color of white or light colored concrete and can be used to add color tones. When the color depends mainly on the fine aggregate, maintaining a consistent gradation is important. This is particularly true for the fractions of the fine aggregate.

**AC3.1.4 Coarse Aggregate**

Selection of aggregate should be governed by the following:

1. The aggregate should have adequate durability properties and be free of staining or deleterious materials. It should be round or cubical in shape, as opposed to slivers with large aspect ratios, to provide for mix properties and appearance.
2. Final selection of colors should be made from concrete samples that have the proper matrix and are finished in the same manner as that planned for production. Some finishing processes change the appearance of the aggregate. If small concrete samples are used to select the aggregate color, the architect/engineer should be aware that the general appearance of large areas tends to be different than indicated by the trial samples.
3. Aggregate with a dull appearance may appear brighter in a white cement matrix than in a gray cement matrix.
4. Weathering may influence newly crushed aggregate. When first crushed, many types of aggregate are bright but will dull slightly with time. Similarly, some of the sparkle caused by acid etching or bush hammering may not last more than a few weeks. The architect/engineer should recognize that samples kept indoors might not represent a weathered appearance.
5. The method used to expose the aggregate in the finished product may influence the final appearance.

The maximum size of coarse aggregate is usually controlled by: (1) the dimensions of the unit to be cast, (2) clear distance between reinforcement, (3) clear distance between the reinforcement and the form, and (4) the desired finish.

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**Commentary**

4. One-fifth of the narrowest dimension between sides of forms.
5. The minimum rib size, unless workability and consolidation methods are such that the concrete can be placed without honeycomb or voids.

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. Aggregate exposed on the face of the precast concrete unit may vary from 1/4 in. (6 mm) up to stones and rubble 7 in. (180 mm) in diameter and larger. Larger aggregates are required for large areas to achieve an acceptable degree of relief. A suggested visibility scale is shown in Table AC3.1.4, Suggested Visibility Scale.

**Table AC3.1.4 Suggested Visibility Scale**

<b>Aggregate Size in.(mm)</b>	<b>Texture Visibility Distance ft (m)</b>
¼ to ½ (6 to 13)	20 to 30 (6 to 9)
½ to 1 (13 to 25)	30 to 75 (9 to 23)
1 to 2 (25 to 50)	75 to 125 (23 to 38)
2 to 3 (50 to 75)	125 to 175 (38 to 53)

Once a sample panel has been approved by the architect/engineer, no other source of exposed aggregate shall be used for the project unless shown to be equivalent in quality, gradation, and color to the approved sample.

Stockpiling of a sufficient amount of aggregate for an entire project will help to minimize color variation and maximize color uniformity. The stockpile may be stored at any convenient location that provides for proper separation from other materials.

The precast concrete manufacturer shall verify that an adequate supply from one source (pit or quarry) of each type of aggregate for the entire job will be readily available.

**A3.1.5 Aggregates for Lightweight Concrete**

**AC3.1.5 Aggregates for Lightweight Concrete**

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

**A3.1.6 Mixing Water**

**AC3.1.6 Mixing Water**

Water shall not contain iron or iron oxides that will cause staining in light colored or white concrete.

**A3.1.7 Admixtures**

**AC3.1.7 Admixtures**

The same brand and type of admixtures shall be

**Standard****Commentary**

used throughout the project where color uniformity is required.

Coloring admixtures or pigments shall conform to the requirements of ASTM C979. Coloring pigments shall be finely ground materials with a proven history of satisfactory color stability when used in concrete. Pigments shall be 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 shall not affect concrete setting time or strength. The amounts of pigment to be used shall not exceed 10% by weight of cement.

Pigments are often added to the mix to obtain colors that cannot be obtained through combinations of 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 due to the high percentage of noncementitious fines introduced to the mix. For this reason, the amount of pigment should be controlled within the prescribed limits to avoid degrading strength and absorption parameters. Different shades of color can be obtained by varying the amount of coloring material or by combining two or more pigments. Brilliant colors cannot be achieved with natural or synthetic pigments. This is due to the low allowable addition rate and the masking effect that the cement and aggregate can create. White portland cement will produce cleaner, brighter colors and should generally 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 color variation. When using dosages from 1% to 5%, the color sensitivity is reduced and more easily controlled. Addition of synthetic iron oxide pigments above 5% will not increase color intensity. The saturation point for natural pigments is closer to 10%.

The coloring pigment should be a natural or synthetic mineral oxide or an organic phthalocyanine dye. Coloring pigments of iron oxides are generally preferred because of better performance. However, such pigments may react chemically with other products, such as surface retarders or muriatic acid, and should be tested prior to use.

Green pigment is very permanent, except in light shades. Some blues are not uniform or permanent. Cobalt blue pigment should be used to reduce uniformity and fading problems. Dark colors accentuate the efflorescence that forms on all concrete surfaces. If the fading of the color over time becomes too objectionable, the color can be restored by washing with diluted hydrochloric acid and rinsing thoroughly. Carbon black is not recommended, due to its extremely fine particle size and tendency to wash out of the concrete matrix. Synthetic black iron oxide will produce a more stable charcoal color.

**Standard****Commentary**

Architects can best specify the desired color by referring to a swatch or color card. A cement color card is preferable but one published by a paint manufacturer is acceptable. An excellent color reference is the Federal Color Standard 595 B, published by the U.S. Government Printing Office.

Efflorescence deposited on the surface may mask the true color and give the appearance of fading even though the cement paste itself has not undergone a color change. In addition, weathering of the pigmented cement paste exposes more of the aggregate. 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.

**A3.2 Reinforcement and Hardware****AC3.2 Reinforcement and Hardware****A3.2.1 Reinforcing Steel****AC3.2.1 Reinforcing Steel**

Galvanized or epoxy-coated reinforcement is generally required when clear cover over the reinforcement is less than 3/4 in. (19 mm). In such cases, the use of galvanizing or epoxy coating should be required in the contract documents and shown on the shop drawings.

**A3.5 Facing Materials****AC3.5 Facing Materials**

Suitable material, such as natural stone, thin brick, ceramic tile, terra cotta, oversized natural or crushed aggregate, may be used as facing materials. Special facing materials shall be properly designed and tested for compatibility with the concrete, precast product, and service conditions.

Once a sample panel has been approved by the architect/engineer, no other source of facing material shall be used for the project unless shown to be equivalent in quality, gradation, and color to the approved sample.

# DIVISION 4 – CONCRETE

## Standard

## Commentary

### 4.1 Mix Proportioning

The properties of concrete mixtures shall be as specified in the project specifications.

Supplementary or replacement cementitious materials other than hydraulic cement may be used in combination with portland or blended cement for economy, reduction of heat of hydration, improved workability, improved strength, and improved durability of the concrete. These materials shall meet the requirements of the following ASTM specifications:

- (ASTM C618) – fly ash, natural pozzolans
- (ASTM C989) – ground granulated blast-furnace slag
- (ASTM C1240) – silica fume

Established concrete mix designs for which strength and performance data exists can be used on the basis of past test results if the concrete is made from the same sources of cement and aggregates.

#### 4.1.1 Qualification of New Concrete Mixes

Concrete mixes for precast concrete shall be established initially by laboratory methods. The proportioning of mixes shall be done either by a qualified commercial laboratory, qualified precast concrete technologist, or quality control personnel. Mixes shall be evaluated by trial batches prepared in accordance with ASTM C192 with production tests performed under conditions that simulate, as closely as possible, actual production. Tests shall be made on all mixes to be used in production of precast concrete units. When accelerated curing is to be used, it is necessary to base the mix proportions on similarly cured test specimens.

Each concrete mix 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 mixes. If these variables are changed, the proportions of the mixture shall be re-evaluated.

### C4.1 Mix Proportioning

Much of the skill, knowledge, and technique of producing quality precast concrete elements center around the proper proportioning of the concrete mix. Before a concrete mix can be properly proportioned, several factors must be known such as the finish, size, and shape of units to be cast. The method of consolidation should be known to help determine the required workability of the mix. 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 extent of exposure to severe weather or other harsh environmental conditions will affect the durability requirements of the concrete mix design.

#### C4.1.1 Qualification of New Concrete Mixes

Accepted methods of selecting mix proportioning are provided in the following publications:

1. Portland Cement Association:  
*Design and Control of Concrete Mixtures*
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 211.3)
  - d. *Specifications for Structural Concrete for Buildings* (ACI 301)

Structural concrete mixes used for most structural precast and prestressed concrete products are proportioned primarily for strength and durability with appropriate use of economical constituent materials to produce a cost effective concrete mix.

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Concrete mixes shall be proportioned and/or evaluated on a per project basis to satisfy project requirements and service conditions such as strength, absorption, volume change, and resistance to freezing and thawing. The mix shall have adequate workability for proper placement and consolidation.

**4.1.2 Specified Concrete Strength**

Concrete strengths shall be determined on the basis of test specimens at time of stripping, transfer of prestress, or the specified age (typically 28 days). A minimum acceptable strength at time of stripping shall be established by the precast plant engineer or the engineer of record and shall be stated on the drawings. When members are prestressed, the concrete shall have a specified compressive strength, for transfer of the prestressing forces and design.

**4.1.3 Statistical Concrete Strength Considerations**

The compressive 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, with no individual test results falling below the specified strength by more than 500 psi (3.5 MPa).

**C4.1.2 Specified Concrete Strength**

A minimum design compressive 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. For structural products, the mix is generally proportioned for strength and durability, with aesthetics as a secondary consideration. Concrete strength is typically specified as compressive strength that is determined at the time of transfer of prestressing forces to the concrete, or as the design strength. A standard age used for determining the official design is 28 days; however, other ages may be specified.

Production requirements for early stripping of units or early prestress transfer and subsequent rapid reuse of forms require high early compressive strengths. The minimum required transportation and erection strength levels are dependent on the shape of the unit, handling, shipping, erection techniques, and the delivery schedule. These requirements often necessitate such high early strength that the resulting 28-day strengths far exceed the specified design strengths requirement.

Design strengths specified for mixes to be used in prestressed concrete cover a wide range of strengths, but are generally higher than typical strength requirements for mild reinforced concrete members. In the absence of other specifications, a minimum design strength of 5,000 psi (34.5 MPa) at 28 days is recommended.

**C4.1.3 Statistical Concrete Strength Considerations**

The average compressive strength, 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)

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- 550 psi (3.79 MPa) if the standard deviation is 300 (2.07 MPa) to 400 psi (2.76 MPa)
- 700 psi (4.82 MPa) if the standard deviation is 400 (2.76 MPa) to 500 psi (3.45 MPa)
- 900 psi (6.20 MPa) if the standard deviation is 500 (3.45 MPa) to 600 psi (4.14 MPa)

These values are based on ACI 318 equations for  $f'_{cr}$  required compressive strength. ACI 318 requires that mixes be proportioned for  $f'_{cr}$  as defined by the larger of the following two equations:

$$f'_{cr} = f'_c + 1.34s \quad \text{or}$$

$$f'_{cr} = f'_c + 2.33s - 500$$

Where

$f'_{cr}$  = required average compressive strength (psi)

$f'_c$  = specified compressive strength (psi)

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, mix proportions should be selected to produce a minimum average strength of:

- 1200 psi (8.27 MPa) greater than the specified strength for required strengths of 5000 psi (34.5 MPa), and below, and
- 1400 psi (9.66 MPa) for required strengths above 5000 psi (34.5 MPa).

**4.1.4 Proportioning to Ensure Durability of Concrete**

Concrete strength and durability shall be achieved through proper consideration of air entrainment, water content, cementitious material content, and workability. Low water to cementitious material ratio (w/cm) 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, w/cm, additives, and admixtures.

**C4.1.4 Proportioning To Ensure Durability of Concrete**

Achieving low absorption rates for the surface of the concrete requires a high-density concrete surface.

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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. High-range water-reducing admixtures (HRWR), also referred to as superplasticizers, shall be in accordance with the requirements of ASTM C494, Type F or G, for normal concrete. For flowing concrete, HRWR shall be in accordance with ASTM C1017, Type 1 or 2. Calcium chloride or admixtures containing chloride ions (Cl<sup>-</sup>), other than impurities from admixture ingredients shall not be used in prestressed concrete. This is to ensure against deleterious concentrations of chloride ions that may cause corrosion of the reinforcement.

Combinations of cement and aggregate 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.

**4.2 Special Considerations for Air Entrainment**

Units subject to freezing and thawing shall be air entrained. When the entrained air content cannot be reliably measured for gap-graded mixes, the dosage of air-entraining agent shall produce an 8%-10% air content in the mortar (material passing the No. 4 (4.75 mm) sieve) or 19%, ±3% 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 used for production control of the fresh concrete.

When air-entrainment is required due to potential exposure conditions such as freeze-thaw, chemical deicers, and/or alternate cycles of wetting and drying, the air content at the point of delivery shall be in accordance with the requirements of Table 4.2.1. For specified compressive strengths greater than

Not all non-cementitious materials that can be added to concrete will necessarily provide any or all of the benefits noted in 4.1. The effect of adding such materials should be carefully investigated in advance of using the products in concrete mixes for the first time.

Because the aggregate occupies the greatest volume of the mix, it is important to select good quality aggregate. The use of poor quality aggregates may result in durability concerns for concrete under harsh environmental service conditions.

**C4.2 Special Considerations for Air Entrainment**

Air is entrained in the mortar fraction of the concrete. In properly proportioned mixes, the mortar content decreases as the maximum aggregate size increases. This allows for a corresponding reduction in the entrained air content.

Air-entrained concrete should begin to exhibit resistance to freeze-thaw damage at a strength of approximately 500 psi (3.45 MPa), provided there is no external source of moisture.

For many mixes with high cement contents and low slumps, a given percentage of air cannot be reliably measured.

For a given w/cm, 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 mix sufficiently to facilitate a reduction in the water content.

**Standard**

**Commentary**

5000 psi (34.5 MPa), a reduction of the air content by 1.0%, as indicated in Table 4.2.1, shall be permitted.

The production of high-strength concrete (6000 psi or greater [41 MPa]) 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 economical to achieve the high-strength requirements without air entrainment.

**Table 4.2.1. Total Air Content 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	5
1-1/2 (38)	5-1/2	4-1/2

1. Air content tolerance is  $\pm 1/2$  percent.

The properties of the concrete constituent materials, mix proportioning mix, and all aspects of mixing, handling, and placing shall be maintained as consistently as possible to help ensure uniformity of the required air content.

Class C fly ash, normally produced with a low carbon content, typically has little to no effect on entrained air or the air-entraining admixture dosage rate. However, Class F fly ashes that generally have a relatively higher carbon content may require a higher dosage of air-entraining admixture to obtain the specified air content.

Typical plant control practice only involves the 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 to be effective for freeze-thaw resistance when the volume of air in the mortar fraction of the concrete (material passing the No. 4 sieve) is approximately  $9\% \pm 1\%$ .

**4.3 Mix Proportioning for Concrete Made with Structural Lightweight Aggregate**

**C4.3 Mix Proportioning for Concrete Made with Structural Lightweight Aggregate**

Structural lightweight aggregate concrete is defined as concrete that:

- (1) is made with lightweight aggregates conforming to ASTM C330,
- (2) has a compressive strength in excess of 2500 psi (17.2 MPa) at 28 days of age when tested in accordance with methods stated in ASTM C330, and
- (3) has an air-dry unit weight not exceeding 120 pcf (1922 kg/m<sup>3</sup>) determined in accordance with ASTM C567.

Mix proportioning methods for structural lightweight aggregate concrete (ACI 211.2) generally differs somewhat from those for normal weight concrete. The main differences that should be accounted for in mix proportioning and production procedures are associated with the aggregate weight, absorption, and rate of absorption. The absorption of water by the aggregate will have little effect on compressive strength if accounted for in the total water content of the mix.

To ensure consistency of the mix, the moisture content of the aggregate must be monitored. Variations in the moisture content will require adjustments in the batching weights of the aggregate and the volume of water to be added to the mix.

**Standard**

**Commentary**

Lightweight concrete can also be proportioned with a combination of lightweight aggregate and normal weight aggregate.

**4.3.1 Lightweight Aggregates – Absorption and Moisture Content**

Lightweight aggregates shall be predampened prior to batching, and the absorbed water shall be accounted for in the mix-proportioning procedure. The supplier of the particular aggregate should be consulted regarding the necessity for pre-dampening 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.

**4.3.2 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 mix proportioning for lightweight aggregate concrete.

**C4.3.1 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 short period prior to the addition of cement and air-entraining admixture to minimize slump loss.

**C4.3.2 Lightweight Aggregates – Gradation**

For normal weight aggregates, the bulk specific gravity of fractions retained on the different sieve sizes are 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 normal weight 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 normal weight aggregates to provide an equal aggregate size distribution by volume.

**Standard**

**Commentary**

**4.3.3 Water-Cementitious Material Ratio for Lightweight Aggregate Concrete**

Lightweight aggregate concrete shall be proportioned by the weight method (ACI 211.2-91) on the basis of an approximate w/cm relationship when the absorption of the lightweight aggregate is known or to be determined.

**4.3.4 Air Entrainment for Lightweight Aggregate Concrete**

The volumetric method of measuring air entrainment, as described in ASTM C173, shall be used to determine air content in lightweight aggregate concrete mixtures.

**4.4 Proportioning for Concrete Workability**

The slump and workability of a mix shall be suitable for the conditions of each individual job, to permit proper consolidation without segregation or excessive bleeding.

**C4.3.3 Water-Cementitious Material Ratio for Lightweight Aggregate Concrete**

If trial mixtures are proportioned by procedures other than the weight method, the net w/cm 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 not available 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.

**C4.3.4 Air Entrainment for Lightweight Aggregate Concrete**

Air entrainment of at least 4.0% 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*.

**C4.4 Proportioning for Concrete Workability**

Consolidating with effective mechanical equipment permits the use of mixes with low workability. Such mixes allow for a lower water content, which typically improves the strength and durability of the mix.

Slump provides a measure of consistency, not necessarily a measure of workability. Other considerations, such as cohesiveness, harshness, segregation, bleeding, ease of consolidation, and finishability, are important factors that cannot be appropriately measured on the basis of slump

**Standard**

**Commentary**

When water-reducing admixtures are used and the concrete begins to lose workability, retempering with the admixtures per the manufacturer's recommendations is permissible. Retempering with water shall only be permitted up to the allowed w/cm.

Very low water-cementitious material ratio mixes known as no-slump or zero-slump concrete used for extruded and machine cast products shall be proportioned in accordance with ACI 211.3, *Standard Practice for Selecting Proportions for No Slump Concrete*.

**4.5 Water-Cementitious Material Ratio**

determination.

Retempering with water increases the w/cm and has the undesirable effect of reducing strength, increasing shrinkage, reducing the cohesion within the mixture, and increasing the potential for segregation and excessive bleeding.

**C4.5 Water-Cementitious Material Ratio**

**4.5.1 General**

The w/cm of the concrete shall not exceed 0.45 by weight with an allowable variation during production of  $\pm 0.02$ . The w/cm shall be limited to the minimum necessary for proper placing and consolidation by means of appropriate vibration.

**C4.5.1 General**

A high w/cm and high total water content of concrete mixes will negatively affect strength, shrinkage, density, absorption, and uniformity of color.

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.

To optimize mixture proportions, the least amount of water necessary to obtain the required slump and workability should be used. With respect to a fixed w/cm, mixtures having the least amount of paste reduce the cost of the concrete. This is due to the cement in the paste typically being the most expensive ingredient of the concrete.

In addition to controlling the w/cm to a low level, the cement content shall be held to the practical minimum amount needed to achieve stripping, transfer, and service strength requirements.

Most water-reducing admixtures are provided as a water solution. 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 mix design calculations. When using silica fume slurry, the water portion of the slurry must be considered as part of the total water content.

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 mixes.

**Standard**

**Commentary**

**4.5.2 Relationship of Water-Cementitious Material Ratio to Strength, Durability and Shrinkage**

The w/cm is one of the fundamental keys governing the strength and durability of the concrete. The proportioning of the concrete mix design shall minimize the w/cm to the maximum extent possible while providing the required workability of the concrete mix. Low w/cm shall be accompanied by controls on total water content to limit shrinkage.

**4.5.3 Relationship of Water-Cementitious Material Ratio to Workability**

Use of suitable workability improving admixtures shall be employed if additional workability is needed in concrete mixes that are already proportioned at the maximum allowable w/cm.

When low workability mixes are used for facilitating specific production operations, the paste content shall be sufficient to ensure that the bond between the concrete and the prestressing strand can be developed.

**4.6 Effects of Admixtures**

Admixtures shall be materials of standard manufacture having well-established records of tests that confirm acceptability of the short-term and long-term effects on the properties of the concrete. Admixtures shall be used in accordance with the manufacturer's recommendations.

When more than one admixture is used in a concrete mix, it shall be verified prior to production that the admixtures do not adversely interact.

**C4.5.2 Relationship of Water-Cementitious Material Ratio to Strength, Durability and Shrinkage**

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 (i.e., the more paste), the greater the drying shrinkage. Also, cement produces heat as it hydrates. High cement contents may produce an undesirable exotherm during curing and crack-producing temperature differentials.

**C4.5.3 Relationship of Water-Cementitious Material Ratio to Workability**

The required water content of concrete is influenced by a number of factors: aggregate size and shape, slump, 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. Conversely, increased temperature, cement content, slump, w/cm, aggregate angularity, and a decreased proportion of coarse aggregate to fine aggregate increase water demand.

Low workability mixes are required for manufactured products such as extruded hollow core planks. This type of concrete is made with very low w/cm and relies on the high compactive effort of the extruding machine to successfully form the product.

**C4.6 Effects of Admixtures**

The development of admixtures to modify and improve the properties of fresh and cured 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 well-proven performers with no adverse 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.

The following minimum standards should be used as a basis for admixture selection:

## Standard

## Commentary

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. For maximum chloride ion content limits in reinforced concrete, reference ACI 318.

When supplementary or replacement cementitious materials are to be included in the concrete mixture, the mix proportioning shall be established by trial mixtures.

1. ASTM C260, *Standard Specifications for Air-Entraining Admixtures for Concrete*
2. ASTM C494, *Standard Specifications for Chemical Admixtures for Concrete*
3. ASTM C666, *Standard Test for Resistance of Concrete to Rapid Freezing and Thawing*
4. ASTM C618, *Standard Specification for Fly Ash and Raw or Calcined Natural Pozzolan*
5. ASTM C989, *Standard Specification for Ground Granulated Blast-Furnace Slag*

Calcium chloride and admixtures containing chloride ions will promote corrosion of steel reinforcement, 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, the following general ranges are provided in ACI 211.1. The percentages are based on the total weight of cementitious material used in the batch for structural concrete.

Class F fly ash – 15% to 25%

Class C fly ash – 15% to 35%

Natural pozzolans – 10% to 20%

Ground granulated blast-furnace slag (GGBF) – 25% to 30%

Silica fume – 5% to 15%

By evaluating the effect on strength, water requirement, time of set, and other important properties, the optimum amount of cementitious materials can be determined.

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). 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

**Standard**

**Commentary**

Provisions shall be made for controlling the quantity and uniform introduction of all admixtures with other concrete components to ensure uniform distribution into the mix.

cement).

**4.7 Storage and Handling of Concrete Materials**

**C4.7 Storage and Handling of Concrete Materials**

**4.7.1 General**

**C4.7.1 General**

Concrete batching plants and operational procedures shall conform to ASTM C94. Concrete batch plants shall be capable of producing concrete of the quality required for structural 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 ensure accurate measurement.

Concrete supplied by an off-site batch plant shall meet the same requirements as on-site batch plant facilities. Such plants shall be certified by the National Ready Mixed Concrete Association (NRMCA).

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.

**4.7.2 Storage and Handling of Aggregates**

**C4.7.2 Storage and Handling of Aggregates**

Aggregate shall be handled and stored in a manner that minimizes segregation and variable moisture content.

Procedures for handling and storage of aggregates are outlined in further detail in ACI 221 and ACI 304, *Recommended Practice for Measuring, Mixing, Transporting, and Placing Concrete*. When aggregates are to be stockpiled, the use of aggregate bins helps to ensure the aggregate remains clean, prevents segregation, and protects against contamination from adjacent stockpiles.

Wet or moist aggregates shall be stockpiled well 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.

**Standard****Commentary**

**Stockpiles** - A hard, clean, and well-drained base shall be provided for aggregate stockpiles. If contamination from underlying material cannot be avoided, the area shall be planked or paved. Stockpiles shall be built in horizontal or gently sloping layers. Conical stockpiles or any unloading procedures involving the dumping of aggregate down sloping sides of piles shall be prohibited.

Aggregates shall be obtained from stockpiles in a manner that ensures a cross section of the stockpile is removed while minimizing segregation. Wheeled or tracked equipment shall not be operated on the stockpiles. This is to prevent breaking and/or contamination of the aggregate. Suitable walls or ample distance between stockpiles shall be provided to prevent intermixing of different materials.

Fine aggregate shall be handled in a damp state to minimize segregation. Stockpiles shall not be contaminated by spillage from swinging aggregate-filled buckets, conveyor belts, clams, or other types of handling equipment.

**Bins** – When bins are used for storing aggregates, separate compartments shall be provided for each type and size of aggregate. The compartments shall be capable of receiving and storing material without cross-contamination.

Bins shall be filled by material falling vertically, directly over the bin outlet. The compartments shall be designed to discharge freely and independently into the weigh hopper. To avoid accumulation of fines in dead storage areas, bottoms of circular bins shall slope at an angle not less than 50 degrees from the horizontal. The bottom of rectangular bins shall slope at an angle not less than 55 degrees from the horizontal.

**Bags** – When bagged aggregates are used, the individual aggregate sizes shall be stored on pallets in a well-drained and reasonably dry area. Fine aggregates shall be stored under dry conditions. Bagged aggregate shall be weighed prior to usage.

**Stockpiles** – Stockpiles of coarse aggregate inevitably tend to accumulate an excess of fines near the base of the stockpile. This material should be periodically removed and discarded to ensure proper gradation is maintained. It is essential that aggregates are uniform and clean to help ensure production of uniform concrete.

**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. Bins should be kept as full as practicable at all times, as breakage and changes in grading will be minimized as the materials are drawn down.

**Bags** – Aggregates bagged in burlap should be protected from moisture to prevent deterioration of the bags. Aggregates stored in polypropylene 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. Different size aggregate should be stored separately.

## Standard

## Commentary

### 4.7.3 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 weather-tight 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 shall be smooth with a minimum bottom slope of 50 degrees from the horizontal for a circular silo and 55 degrees 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 cut-off 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 type 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 the oldest cement is used first.

### 4.7.4 Storage and Handling of Admixtures

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 weather-tight containers or tanks that are clearly labeled by

### C4.7.3 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. 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, texture, or the presence of coarse particles may be evidence of a contamination problem.

**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.

### C4.7.4 Storage and Handling of Admixtures

The requirements for storage of powdered admixtures are generally the same as those for storage of cement.

**Standard**

**Commentary**

the type, brand, and manufacturer of the admixture.

Provision shall be made to provide 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, a calibrated holding tank shall be part of each system. This is required so plant operators can visually verify that the proper amounts of each admixture are batched.

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 manufacturer's 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

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 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.

**Standard**

**Commentary**

tank after batching and prior to introduction into the mixer. If the same dispensing equipment is used for noncompatible admixtures, the dispenser shall be flushed at the end of each cycle.

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.

Metakaolin shall be handled and stored in a similar manner as cement.

**4.8 Batching Equipment Tolerances**

Batching equipment shall be maintained and operated in accordance with ASTM C94. The quantities of ingredients used for each batch shall be recorded separately.

When measuring by bulk volume, batching shall be in accordance ASTM C685 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 the scale capacity.

For ingredients batched by weight, the accuracy tolerances required of the batching equipment should be applicable for batch quantities between 10% and 100% of the scale capacity.

For water or admixtures batched by volume, the required accuracy tolerances shall be applicable for all batch sizes from minimum to maximum batcher ratings.

Operation and maintenance of batching equipment shall be provided in a manner that ensures the concrete ingredients are consistently measured.

For individual batching equipment, the following tolerances shall apply based on the required scale reading:

- Cement and other cementitious material:  $\pm 1\%$  of the required weight of material being weighed, or  $\pm 0.3\%$  of scale capacity, whichever is greater.

Silica fume is provided in bulk, bags, or drums (slurry).

Metakaolin is provided in a powder form in bags or bulk.

**C4.8 Batching Equipment Tolerances**

The range of tolerance control, weight control limitations of batching equipment, and batching controls are addressed in the *Concrete Plant Mixer Standards*, published by the Concrete Plant Manufacturers Bureau.

**Standard**

**Commentary**

- 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 greater.
- 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 greater.

Water: The mechanisms in most commercial water meters cannot respond to quantities in less than 1-gallon increments.

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.

For cumulative batching equipment without a tare compensated control, the following tolerances shall apply to the required cumulative scale reading:

- Cementitious materials and 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 greater.

For volumetric batching equipment, the following tolerances shall apply to the required volume of material being batched:

- Water:  $\pm 1\%$  of the required weight of material being batched, or  $\pm 1$  gallon, whichever is greater.
- Admixtures:  $\pm 3\%$  of the required volume of material being batched but not less than  $\pm 1$  oz (30 ml) 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 with the weight tolerance waived.

Water: For batch sizes less than 2 cubic yards, water volume must be controlled to  $\pm 1/2$  gallon to meet the w/cm tolerance requirements.

Aggregates: In some instances, the accurate control of concrete with lightweight aggregate is more feasible measuring by bulk volume than by weight.

**Standard**

**Commentary**

**4.9 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 to 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 not be less than 660 lbs per cubic yard (392 kg per cubic meter) 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 not be less than 3,300 lbs per cubic yard (1,958 kg per cubic meter) of the rated batcher capacity.

All scales shall be maintained to provide accuracy within 1% of the loads weighed under operating conditions or  $\pm 0.20\%$  of scale capacity throughout the range of use. For direct digital readout, 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 mix 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.

**C4.9 Scale Requirements**

Accurate weighing of the batch ingredients is critical to ensure that the characteristics of the mix, as designed and proven in the trial mix process, are achieved in production.

Since variations in cement and cementitious material batch weights are more important to the overall performance of the mix than are small variations in aggregate weights, separate scales should be used so that potential errors in cement weights are readily apparent.

**Standard**

**Commentary**

For calibration of scales, standard test weights aggregated to at least 500 lbs (227 kg) (each accurate to 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.

Confirmation of accurate scale performance can only be determined by proper calibration checks. This is an important aspect of overall concrete quality control.

**4.10 Requirements for Water Measuring Equipment**

**C4.10 Requirements for Water Measuring Equipment**

The reading face capacity or the sum of weigh-beam capacities of a scale for the water batcher shall not be less than 320 lbs (145 kg) or 38 gallon per cubic yard (188 liters per cubic meter) of rated batcher capacity.

Water meters should conform to the Standards of the American Water Works Association.

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.

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, it shall be measured accurately in a separate tank and accounted for in determining the amount of additional water required.

Calibration of water measuring devices shall be performed at intervals not exceeding three months or whenever there is reason to question accuracy.

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.

**4.11 Requirements for Batchers and Mixing Plants**

**C4.11 Requirements for Batchers and Mixing Plants**

**4.11.1 General**

**C4.11.1 General**

The batch plant shall be capable of providing sufficient quantities of concrete to ensure continuous casting operations. The concrete ingredients shall be properly proportioned and mixed to the desired uniformity and consistency.

It is not the purpose of this article to specify any particular type of concrete plant.

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; or fully automated, electronically controlled plants in which mixes are controlled by means of selectors, punch cards, or computer memory.

**Standard**

**Commentary**

Batchers 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. Batchers shall be capable of receiving the rated load and maintaining a separation distance to prevent contact of the weighed 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. Systems shall contain interlocks that prevent batcher charging and discharging from occurring simultaneously and in the event of electrical or mechanical malfunctions, ensure that materials cannot be overbatched. Provision shall be made for removal of material overloads.

The batchers 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 and weighing equipment used to meter cementitious material shall be provided with a dust seal between the charging mechanism and batcher. 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.

**4.11.2 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. Concrete may be mixed by any of the methods listed in Article 4.15.2.

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 the concrete is of consistent quality, and operations are performed in accordance with ASTM C94.

**C4.11.2 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 mix. Consistency meters, such as those operating from

**Standard**

**Commentary**

Mixers with a rated capacity of 1 cubic yard (0.76 cubic meter) or larger shall be in accordance with the requirements of the *Concrete Plant Mixer Standards* of the Concrete Plant Manufacturers Bureau, 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.

**4.11.3 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 to mix quantities greater than the quantity recommended by the mixer manufacturer. The rate of rotation of the drum or blades for truck or stationary mixers shall be in accordance with the manufacturer's recommendations.

**4.11.4 Maintenance Requirements for Concrete Mixers**

All mechanical aspects of mixers or agitators, such as water-measuring and discharge apparatus, condition of blades, speed and 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

the amperage draw on the electric motor drives for revolving drum mixers, may also prove useful. However, the most effective measure for monitoring the concrete uniformity is a regularly scheduled program of fresh concrete tests. Such tests include unit weight, air content, slump, coarse aggregate content, and temperature.

For a description of the various mixer types, refer to the *Concrete Plant Mixer Standards* of the Concrete Plant Manufacturers Bureau, Mixer Manufacturers Division.

**C4.11.3 Mixer Placard Requirements**

Low-slump concrete may require smaller loads than the rated mixer capacity.

**C4.11.4 Maintenance Requirements for Concrete Mixers**

A preventative maintenance program for concrete mixers and associated equipment is critical to the production of uniform quality concrete.

Cement lumps in the mix may indicate ineffective mixing caused by worn blades or a dirty mixer.

**Standard**

**Commentary**

**4.12 Concrete Transportation Equipment**

**C4.12 Concrete Transportation Equipment**

**4.12.1 General**

**C4.12.1 General**

Bottom dump buckets or hoppers shall be designed to allow for 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 mix. If dump buckets are used, the side slopes of transportation containers shall be no less than 60 degrees measured from the horizontal. Controls on the gates shall permit opening and closing during any portion of the discharge cycle.

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.

All conveying equipment shall be thoroughly cleaned prior to casting, between different mixes, or at frequent intervals during prolonged castings.

**4.12.2 Requirements for Concrete Agitating Delivery Equipment**

**C4.12.2 Requirements for Concrete Agitating 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 at the specified slump. Low slump concrete shall be batched and mixed in smaller batches if required for ensuring efficient discharge of the concrete from the mixer.

Prior to the start of a full production run or units that require low slump/workability mixes, the condition of the transportation equipment should be verified.

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 thoroughly mixed and discharged with a satisfactory degree of uniformity as defined in ASTM C94.

**Standard**

**Commentary**

**4.13 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 quality of the end product.

Chutes, hoppers, buckets, or gates on placing and transportation equipment shall not restrict the use of a specified low w/cm or low slump concrete.

Chutes shall be metal or metal-lined with a rounded bottom, rigid, and protected from overflow. Chutes shall be sloped at an angle between 30 degrees and 45 degrees, measured from the horizontal.

Chutes having a length that causes segregation (more than 20 ft [3 m]) or having a slope greater than 45 degrees from the horizontal may only be used if the concrete materials are recombined by a hopper or other suitable means before placement.

**4.14 Batching and Mixing Operations**

**4.14.1 General**

All concrete shall be accurately batched and properly mixed to a uniform consistency.

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. Materials shall enter the mixer at a point near the center of the mixer.

Information on mix designs, batching, and mixing procedures shall be recorded and maintained as required in Division 6 for quality control records.

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, mix designation, design slump, and time of batching.

**C4.13 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 mixes.

**C4.14 Batching and Mixing Operations**

**C4.14.1 General**

Batching is the process of weighing or volumetrically measuring, and introducing into the mixer, the ingredients for a batch of concrete. Consistency and accuracy in all phases of batching and mixing are key to ensuring a quality and uniform mix. Each mix should be batched in the same sequence and mixed for the same length of time.

Proper batching and mixing procedures should produce uniform concrete with the required material proportions.

**Standard**

**Commentary**

**4.14.2 Batching of Aggregates**

**C4.14.2 Batching of Aggregates**

Low variation of gradation, as batched, is necessary for the production of uniform concrete.

Under normal conditions, all of the aggregates shall be charged into the mixer after an initial 5% to 10% of the mix water has been charged.

Batch weight of normal weight 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. 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.

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 batching fine aggregates is done by weight.

If in-line moisture meters are not used, the free moisture of the fine aggregate shall be determined at least daily, 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.

Refer to Article 4.15.7 for batching of lightweight aggregate.

**4.14.3 Batching of Cement**

**C4.14.3 Batching of Cement**

Cement shall be batched in a manner that ensures uniform distribution in the mix. Cement shall be charged with the fine and coarse aggregates but shall enter the stream after approximately 10% of the aggregates are in the mixer. When heated water is used to warm the mix, the addition of the cement shall be delayed until most of the water and aggregate have been charged into the mixer.

When heated water is used in cold weather, the order of charging the mixer may require some modification to prevent a possible rapid stiffening effect as a result of the combination of hot water directly with cement. Geographic climate variations and experience may dictate minor differences in methods.

Free fall of cement shall not be permitted. Cement shall flow from the hopper into the stream of aggregates through a suitable enclosure chute.

Of all the constituent elements of the concrete mix, proportioning of the cement in the mixture is the most important determinant of the characteristics of the concrete. 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.

If batching cement 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. Partial bags shall not be used unless weighed.

**Standard****Commentary****4.14.3 Batching of Water**

When mixing normal weight concrete, a portion of the mixing water (between 5% and 10%) shall precede, and a like quantity should follow the charging of other constituent materials into the mixer. The remainder of the water shall be introduced uniformly with the other materials. Charging of water shall be completed within the first 25% of the mixing time. For mixes of 1 cubic yard (0.76 cubic meter) capacity or less, the aggregates may be placed into the mixer first, with the cement and water introduced subsequently and at the same time.

**4.14.5 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.

**C4.14.4 Batching of Water**

Next to the 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 mix, stringent controls on the handling, measurement, and introduction of water to the mix should be observed.

**C4.14.5 Batching of Admixtures**

Most admixtures are furnished in liquid form and often do not require dilution or continuous agitation to maintain 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 agitation 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 handling, storage, and measurement of admixtures addressed herein should be observed.

Admixtures should be charged into the mixer in the same sequence for every batch. Changing the timing or sequence that the admixture is added during mixing may vary the effectiveness of the admixture. Regardless of whether 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 mix. Liquid chemical admixtures should not be added directly to the cement or to dry, absorptive aggregate. Liquid admixtures should, in most cases, be charged with the last portion of mix water. The entire amount of nonretarding admixtures shall be added prior to the completion of the addition of the mixing water. The

**Standard**

**Commentary**

Tanks, conveying lines, and ancillary equipment shall be drained and flushed on a regular basis per manufacturer's 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.

A manually operated admixture dispenser system shall have a valve with a locking mechanism to ensure the admixture is completely discharged.

When finely divided mineral admixtures are used in bulk, the weighing sequence shall be cement first and admixture 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 which 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 mix.

Metakaolin shall be added to the batch with the cement or after all other ingredients have been charged.

addition of retarding admixtures shall be completed within 1 minute 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.

If more than one admixture is being used through a single dispenser without flushing of the dispenser with water after each cycle, it is necessary to ascertain that the admixtures are compatible and that the mixing of the admixtures prior to introduction in the mix will not be detrimental.

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 mix. This may lead to nonuniform consistency throughout the mix.

Care shall 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).

**Standard**

**Commentary**

**4.15 Mixing of Concrete**

**C4.15 Mixing of Concrete**

**4.15.1 General**

**C4.15.1 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 mix is uniform in appearance.

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. In the discharge of component materials from batching facilities to the mixer, the solid materials shall, if possible, be arranged in the charging hoppers to allow for proportional amounts of each material to be ribbon fed to the mixer. The minimum mixing time or number of revolutions shall be established for ensuring that the necessary level of uniformity and consistency is obtained.

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 mixes require longer mixing times to improve workability and help eliminate the potential for surface voids and other consistency related problems.

**4.15.2 Methods of Concrete Mixing**

**C4.15.2 Methods of Concrete Mixing**

Concrete shall be mixed by one of the following methods:

1. Central mixed concrete
2. Shrink mixed concrete
3. Truck mixed concrete

Definitions:

1. Concrete mixed in a central stationary mixer and delivered to the casting area by buckets, truck mixer, truck agitator or nonagitating trucks.
2. Concrete that is partially mixed in a stationary mixer then mixed completely and delivered to the casting site in a truck mixer.
3. Concrete that is completely mixed in a truck mixer as it is delivered to the casting site.

All requirements for mixing of concrete, as given in this Article, are valid for both normal weight aggregates as specified in ASTM C33 and for lightweight aggregates for structural concrete, as specified in ASTM C330.

The time from the start of concrete mixing to placement shall not exceed 1 hour. Retempering (with water) of concrete which has started to stiffen shall not be allowed.

The practice of adding superplasticizer to counteract slump loss must be carefully monitored to avoid potential uniformity problems.

**Standard****Commentary****4.15.2 Mixing Time and Concrete Uniformity**

Mixing time shall be measured from the time all cement and aggregates are charged into the mixer drum. All water shall be in the drum by the end of the first one-fourth of the established mixing time.

Mixing time for air-entrained concrete shall be verified and controlled to ensure the specified air content.

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. The mixer performance shall be determined from tests using two samples taken no more than 15 minutes apart. The first sample shall be obtained after discharge of approximately 15% of the batch and the second after 85% of the batch.

When uniformity sampling is performed, slump tests, taken at the time of sampling, shall be made to check the relative degree of uniformity. If the slumps differ more than the specified values in Table 4.15.3, the mixer shall not be used unless corrective measures are taken.

**C4.15.3 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 mixes, grinding of aggregates, and loss of workability. Concrete mixing procedures should be established for each type of mixer. Variations in mix 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 the 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 time up to about 5 minutes, 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.

Scheduling of operations should be controlled to prevent delays in the period between charging the mixer and depositing the concrete in the forms. Such delays may result in nonuniform concrete.

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 periodically, preferably after each production day.

**Standard**

**Commentary**

**Table 4.15.3 Requirements for Uniformity of Concrete (from ASTM C94)**

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: If average slump is 4 in. or less, in. If average slump is 4 to 6 in. If superplasticizers used in mix, in.	1.0 1.5 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

**4.15.4 Mixing Time – Stationary Mixers**

Unless otherwise recommended by the mixer manufacturer, the minimum mixing time for stationary mixers shall be one minute for batches of 1 cubic yard (0.76 cubic meter) or less. This mixing time shall be increased by at least 15 seconds for each cubic yard, or fraction thereof, in excess of 1 cubic yard (0.76 cubic meter). The mixing time shall be increased when necessary to ensure the required uniformity and consistency of the concrete. Both undermixing and overmixing shall be avoided.

**4.15.5 Mixing Time – Shrink Mixing**

When a stationary mixer is used for the partial mixing of the concrete during shrink mixing operations, the time may be reduced to a minimum of 30 seconds, followed by not less than 50 revolutions or more than 100 revolutions at mixing speed in a truck mixer. Any additional revolutions in the truck mixer shall be at agitating speed in accordance with mixer manufacturer's recommendations.

**4.15.6 Mixing Time – Truck Mixing**

For mixing in a truck mixer loaded to the maximum rated mixing capacity, the number of revolutions of the drum or blades at mixing speed shall not be less than 70 nor more than 100, unless special conditions

**C4.15.4 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.

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 blades should be reduced to agitating speed, or the mixer should be stopped in intervals to prevent overmixing.

**C4.15.6 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

**Standard**

**Commentary**

necessitate additional mixing time. If the batch is at least 1/2 cubic yard (0.4 cubic meter) 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.

mixing speed, mixing time, and the addition of water.

A minimum of 100 revolutions at a speed of at least 15 revolutions per minute shall be used for 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.

**4.15.7 Special Batching and Mixing Requirements for Lightweight Aggregates**

**C4.15.7 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.

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 mix is used for the first time, the mixing and handling procedures should be checked to ensure they are adequate to produce uniform concrete of the quality specified. In such a case, the aggregate producer's recommendations may be particularly helpful.

Lightweight aggregate may require predampening 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, predampening prior to mixing is not required. If the lightweight aggregate absorbs more than that shown above, it shall be predampened and a mixing procedure developed that is shown to produce concrete of uniform quality.

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.

**4.15.8 Cold Weather Mixing**

**C4.15.8 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.

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.

**Standard**

**Commentary**

When exposure to cold weather is severe, due either to low air temperature or because the concrete sections are thin, the temperature of the fresh concrete shall be increased by heating to ensure 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 180°F (82°C).

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 avoid the possibility of premature stiffening 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 (38°C) before the cement is added.

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.

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.

**4.15.9 Hot Weather Mixing**

**C4.15.9 Hot Weather Mixing**

The concrete temperature at the mixer shall be maintained below a maximum of 95°F (35°C).

Care should be taken in hot climates to protect batch-material storage bins and waterlines 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. 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 mix.

If high temperatures are encountered, the mix ingredients shall be cooled before or during mixing. 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. Liquid nitrogen may also be used to cool the aggregates.

As the concrete temperature increases, the setting rate also increases. Because higher temperatures generally reduce the time period for optimal workability, proper scheduling of the concrete placement is critical.

**4.16 Requirements for Transporting and Placing of Concrete**

**C4.16 Requirements for Transporting and Placing of Concrete**

**4.16.1 General**

**C4.16.1 General**

Proven and effective procedures for placing concrete are described in detail in the following publications of the American Concrete Institute:

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

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1. *Recommended Practice for Measuring, Mixing, Transporting, and Placing Concrete* (ACI 304)
2. *Recommended Practice for Hot Weather Concreting* (ACI 305)
3. *Recommended Practice for Cold Weather Concreting* (ACI 306)

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, partially completed products shall be washed out of the forms or rejected.

### 4.16.2 Transporting and Placing Concrete

Concrete shall be transported from the mixer to the forms in the shortest possible time and in such a manner as to prevent segregation or loss of mortar.

Before beginning casting operations, hardened concrete and foreign matter shall be removed from the surfaces of the transportation and placing equipment. Free water or excess grout shall not be permitted to drip from transport equipment onto previously finished concrete.

### 4.16.3 Preventing Aggregate Segregation

Procedures and arrangements of equipment shall be used that result in placing concrete in a uniform and compacted condition without segregation. Placing methods shall preserve the quality of the concrete in terms of w/cm, slump, uniformity, air content, and

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with an increase in slump, 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 occurs (resulting in honeycomb) or uniformity of appearance is affected; in which case, a limit of 3 to 5 ft (0.9 to 1.5 m) may be adequate. However, to protect spacers, embedded features, form surfaces, and to prevent displacement of reinforcement, concrete fall should be limited to a few feet 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 so that it may be placed while the previous layer is still plastic. This will allow for proper consolidation between layers.

### C4.16.2 Transporting and Placing Concrete

The effects of transporting the concrete to the placing site should be evaluated and procedures 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.

The use of nonagitating trucks to transport concrete containing silica fume or metakaolin is not recommended.

Regardless of the manner of transportation, concrete shall be discharged into the forms while in its original mixed or plastic state. Retempering by adding water and remixing concrete that has started to stiffen shall not be permitted.

As concrete is placed into the forms, 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 reinforcing or embedments that will extend out of the concrete section.

### C4.16.3 Preventing Aggregate Segregation

Obvious clusters and pockets of coarse aggregate are objectionable and shall be scattered prior to covering with subsequent lifts of concrete to ensure against rock pockets and honeycombing in the completed unit.

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homogeneity.

Scattered individual pieces of separated coarse aggregate are not objectionable if readily enclosed and consolidated into the concrete.

Concrete should not be deposited in the forms and then leveled or moved horizontally into final position. Such practices result in segregation, as the mortar tends to flow ahead of coarser material. This can result in visible flow lines on the exposed surface. Placing concrete as near to its final location as possible minimizes segregation, the potential for increased entrapped air, and other surface-related aesthetic concerns. Once concrete segregates due to improper handling, the segregation cannot be corrected by subsequent placing and consolidation operations.

**4.16.4 Preparation of the Forms**

Prior to concreting, the forms shall be cleaned. Loose and other unwanted materials, such as tie wire clippings, shall be removed by compressed air, vacuum cleaning, or other acceptable methods. If required, a form release agent shall be uniformly applied to all form surfaces that will be in contact with the concrete to provide easy release and stripping of the element from the forms. Form release agent shall be applied prior to placement of the steel and shall provide for the required concrete surface finish.

**C4.16.4 Preparation of the Forms**

Preparation of the forms also involves the setting of form surfaces, bulkheads, and features to within specified dimensional tolerances.

**4.16.5 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.

**C4.16.5 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 production response to severe weather conditions should be developed for use whenever weather conditions dictate.

Concrete shall be placed at a 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 305, *Recommended Practice for Hot Weather Concreting*. Measures shall be taken during severe weather conditions to ensure the concrete remains plastic during placement and finishing operations and that favorable curing conditions are provided thereafter.

The optimum temperature for concrete placement is recommended as 70°F (21°C).

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**4.16.6 Placing Concrete in Wet and Rainy Conditions**

The producer 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.

**4.16.7 Placing Concrete in Hot or Windy Conditions**

For concrete placed in hot weather conditions, the temperature shall not be above 95°F (35°C) unless placement at a higher temperature is confirmed to be acceptable in accordance with ACI 305, *Recommended Practice for Hot Weather Concreting*. 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.

**4.16.6 Placing Concrete in Wet and Rainy Conditions**

**C4.16.7 Placing Concrete in Hot or Windy Conditions**

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 (35°C) as an upper limit, the maximum temperature should be reduced until problems are eliminated.

If hot and/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 the 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 exposed concrete surfaces are finished or 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 170°F (77°C), unless special measures to control concrete temperature as outlined in ACI 305, *Recommended Practice for 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 hours, as such membranes do not cool the concrete as well as wet curing methods.

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The requirements of ACI 305, *Recommended Practice for Hot Weather Concreting*, shall be observed when these conditions are present.

#### 4.16.8 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 306, *Recommended Practice for Cold Weather Concreting*, shall be observed.

#### 4.16.9 Placing Concrete

Concrete shall be carefully placed, as nearly as possible, in final position and worked into all details of the forms. The whole mass shall be consolidated by proper vibration. Once placed, concrete shall only be spread with solid-faced tools to prevent concrete segregation. It shall be placed in successive layers and in a manner that the flow is away from corners and ends.

Concrete shall not be subjected to any procedure that will cause segregation or flow lines. Concrete

10. Set-retarding admixtures, which can delay the concrete setting time and provide a longer period for placing and finishing.
11. When the temperature of steel is greater than 120°F (49°C), steel forms and reinforcement should be sprayed with water just prior to placing the concrete. The surface of the forms should be free of visible water droplets prior to placing the concrete to avoid potential surface finish problems.

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 and/or drying weather conditions.

#### C4.16.8 Placing Concrete in Cold Weather Conditions

Concrete can be placed successfully when ambient temperature falls below 40°F (5°C). This is done by heating the forms to maintain a minimum concrete temperature of 50°F (10°C). The existence of windy and cold conditions may dictate added protection to maintain the temperature of the forms and the concrete after placement.

The combined temperature of the concrete and forms should ensure that the concrete has a minimum temperature of 50°F (10°C) after placement. Concrete curing temperatures must be maintained above 50°F (10°C) for the cement hydration process to properly progress.

#### C4.16.9 Placing Concrete

When mixtures of dry or stiff consistencies are required, the placement rate should be slow enough to permit proper vibration. This will help to prevent bug holes and honeycombing. However, placing concrete too slowly can produce layer 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 will increase the possibility of trapping more and larger air voids.

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placing on a slope shall begin at the lower end of the slope and progress upward thereby increasing consolidation of the concrete and avoiding segregation.

**4.16 Consolidation of Concrete****4.17.1 General**

Concrete shall be uniformly consolidated by internal or external vibration, spading, impact, or a combination of these methods that ensures adequate consolidation of the concrete comprising the finished product.

Consolidation of concrete mixes shall accomplish full coating of the coarse aggregate and reinforcement with cement paste. Air pockets around reinforcement, that can create potentially corrosive environments, shall be avoided by selecting proper consolidation methods.

After the proper vibrating equipment has been selected, it shall be operated by trained personnel. Concrete vibration shall be performed with proper timing and spacing to ensure adequate consolidation.

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 unacceptable surface defects such as honeycombing, aggregate or mortar pockets, and excessive air bubbles are noted, the placement and vibration procedures shall be revised to ensure proper consolidation.

Vibration procedures shall be established at the beginning of each project that will ensure adequate concrete consolidation in the various types of products to be cast.

Cold joints shall be avoided unless specifically accounted for in the design.

**C4.17 Consolidation of Concrete****C4.17.1 General**

Vibration should be distributed so the concrete is thoroughly consolidated, producing a dense and uniform mass. It shall also ensure surfaces that are as free of imperfections or blemishes as possible. The optimum time of vibration depends on the type of vibrator, the mix characteristics, and the configuration of the forms and reinforcement. Reducing the vibration time on the last lift in returns will result in increased bug holes.

The selection of the most appropriate vibrator or vibration method involves factors such as:

1. Size, shape, type and stiffness of the forms.
2. Concrete mix and consistency.
3. Prior experience.

It is difficult to damage properly proportioned and mixed concrete by excessive vibration, provided the forms are properly designed. Problems stemming from inadequate vibration are far more common than problems associated with excessive vibration.

Cold joints may be required for certain types of members with complex dimensions that cause forming and production difficulties.

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### 4.17.2 Consolidation of Lightweight Concrete

In consolidation of lightweight concrete, precautions shall be taken to avoid aggregate floatation caused by overvibration.

### 4.17.3 Consolidation of Complex Precast Concrete Products

The layers of concrete shall be placed level to minimize vibrator-induced flow of the concrete. High spots shall be leveled by hand or by mechanical screeding.

### 4.17.4 Use of Internal Vibrators

Workers shall be trained in the proper use of internal vibrators. Vibrators shall not be allowed to contact forms for exposed concrete surfaces. Internal vibrators shall not be inserted closer to the form than 2 to 3 in. (50 to 75 mm). Care shall be taken to avoid vibrator contact with the reinforcement and to avoid displacing cast-in hardware. When internal vibrators are used to consolidate concrete around epoxy-coated steel reinforcing bars, the vibrators shall be equipped with rubber or nonmetallic vibrator heads to avoid damaging the epoxy coating.

### C4.17.2 Consolidation of Lightweight Concrete

In consolidation of lightweight aggregate concrete, care should be taken not to overvibrate. Since the coarse aggregate particles are the lightest solid ingredients in the mix, overvibration can cause the particles to rise. This may lead to finishing problems and the strength to be nonuniform through the depth of the member. The use of mixes with a slump of less than 4 in. (100 mm) helps to prevent segregation during handling, consolidation, and finishing operations.

### C4.17.3 Consolidation of Complex Precast Concrete Products

When large production runs of elements involving complex shapes are planned, it will be cost effective to evaluate alternative consolidation methods in order to identify those methods and procedures that give the most consistent and satisfactory results.

### C4.17.4 Use of Internal Vibrators

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.

The distance between vibrator insertions should generally be about 1 to 1-1/2 times the radius of action, or such that the area visibly affected by the vibrator overlaps the adjacent, vibrated area by a few inches. The vibrator shall not be inserted within 2 ft (0.6 m) of any leading (unconfined) edge.

The vibration frequencies that affect the aggregates and fines of a concrete mix range from 1,200 to 14,000 vibrations per minute (VPM). The lower frequencies activate the large diameter particles, and the higher frequencies affect the fines and cement in the mix. High frequency vibration better ensures complete coverage of larger particles with paste. 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 that contact the forms of exposed concrete surfaces may mar and disfigure the concrete surface. Internal vibrators inserted close to the form may cause the coarse aggregate to be driven away from the form.

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**4.17.5 Use of External Form Vibrators**

The size and spacing of form vibrators shall be such that the proper intensity of vibration is distributed evenly over the desired area of the form.

**4.17.6 Use of Surface Vibrators**

Surface vibrators shall be designed and used in a manner that prevents separation or displacement of the mix as a result of suction between the concrete and the vibrator 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.

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.

**4.17.7 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

face producing local pockets of fine material (stinger marks) on the surface. Vibration of reinforcement may cause reinforcing steel reflection features visible in the surface of the finished product.

To consolidate “flowing” or high slump concrete, use a large amplitude (i.e., large diameter) internal vibrator 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. When this occurs, the consolidation effort should be reduced. The high-slump, self-leveling characteristics of flowing concrete may appear to not need consolidation. However, as a minimum, nominal vibration should be provided to eliminate large air voids.

**C4.17.5 Use of External Form Vibrators**

Proper spacing of external form vibrators is a function of the type, stiffness and shape of the form, depth and thickness of the concrete, force output and frequency of vibrator, workability of the mix, and vibrating time. Determining the optimum placement and spacing of external vibrators may require trial production runs.

Forms should be placed on elastomeric isolation pads or other resilient-based material to prevent transmission and loss of vibration energy to the supporting foundation.

**C4.17.6 Use of Surface Vibrators**

Surface vibrators are used to consolidate thin layers of precast concrete mixes. Typical types of surface vibrators include vibrating screeds, vibratory tampers, hand jitterbugs, and bull floats with mounted vibrators. Vibrators mounted on bull floats should be mounted so that the shaft of each vibrator rotates in opposite directions.

**C4.17.7 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.

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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 methods. The vibrators shall be positioned to ensure dead spots are eliminated and the most uniform vibration is attained.

The frequency and amplitude of vibrating forms and vibrating tables equipped with external vibrators should be determined at sufficient points to establish the level of uniformity.

**4.18 Requirements for Curing Concrete**

**C4.18 Requirements for Curing Concrete**

**4.18.1 General**

**C4.18.1 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 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.

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 other variables. 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.

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.

Protection of concrete surfaces against moisture loss to prevent shrinkage cracking of concrete that contains silica fume, metakaolin, or other pozzolans, shall begin immediately after finishing.

ACI 308, *Standard Practice for Curing Concrete*, describes various curing procedures in detail.

**4.18.2 Curing Temperature Requirements**

**C4.18.2 Curing Temperature Requirements**

The concrete in the form shall be maintained at a temperature of not less than 50°F (10°C) during the curing period (prior to reaching stripping strength). The time between placing of concrete and the start of curing shall be minimized in hot or windy weather to prevent loss of moisture.

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.

During the initial curing period, positive action shall be taken to provide heat, if necessary to maintain minimum temperatures, and to prevent loss of moisture from the unit. Curing materials or methods shall not allow one portion of an element to cure differently than

Retention of the heat released by the hydration of the cement can be used advantageously by precasters 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

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other portions of the element.

differential shrinkage of the concrete, which can lead to warping of the element.

The maximum curing temperature shall not exceed 180°F (82°C).

**4.18.3 Curing to Attain Specified Stripping or Release Strength**

**C4.18.3 Curing to Attain Specified Stripping or Release Strength**

Curing shall be performed until the stripping strength as indicated on the production drawings has been achieved. The stripping strength and strength at transfer of prestress shall be set by the design engineer, based on the characteristics of the product. It shall be high enough to ensure that the stripping and transfer of prestress does not have a deleterious effect on the performance of the final product.

Stripping or prestress transfer strengths are typically specified at a minimum of 2000 psi (13.8 MPa) for non-prestressed units and 3000 psi (20.7 MPa) or greater for prestressed units. Specified release strengths higher than this may require special mix designs, special curing provisions or longer curing cycles.

The stripping, transfer of prestress, or handling strength of the product shall be determined by test specimens cured under the same conditions as the product.

Well 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.

In addition to the standard test cylinders cured in accordance with ASTM requirements, additional test cylinders shall be made and cured similarly to the units for estimating critical shipping or erection strengths.

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.

**4.18.4 Monitoring of Concrete Curing Temperatures**

**C4.18.4 Monitoring of Concrete Curing Temperatures**

Concrete elements cured using the application of heat (or solar radiation) to accelerate curing shall be monitored to assure that the minimum and maximum concrete temperatures, rates of heating, and the rate of cooling specified herein are not exceeded.

Careful monitoring of concrete curing temperatures, and correlation with respect to stripping or release strengths, can be effectively used to optimize the curing cycle.

The selection of locations for concrete temperature monitoring shall be made to measure the likely maximum and minimum temperature or rate of temperature change.

Temperature monitoring locations should be based on the location of heating or cooling sources, the configuration and design of the form and insulating enclosure, and the cross-sectional dimensions and configuration of the product. Reference Article 2.2.6 for additional information.

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**4.19 Accelerated Curing of Concrete**

**C4.19 Accelerated Curing of Concrete**

**4.19.1 General**

**C4.19.1 General**

Accelerated curing procedures shall be developed to optimize the concrete strength development while ensuring the long-term durability of the concrete.

Accelerated curing is an important aspect of many precast concrete operations, which rely on a daily production cycle for ensuring economical production.

For new concrete mix designs or accelerated 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, and specimens that receive “standard curing” in accordance with ASTM C31. 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.

Temperature guidelines for accelerated curing are as follows:

1. The controlling temperatures shall be those actually achieved within the concrete elements, not ambient temperatures of the curing area.
2. Accelerated curing shall be started after the concrete has attained initial set, determined in accordance with ASTM C403, *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 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 in the range of 3 to 8 hours after batching. The length of the preset period is dependent on factors such as the type of cement, use of admixtures, w/cm, temperature, and other mix characteristics. Because of the wide possible variation of initial set times, determination of the actual initial set time per ASTM C403 is very important.

For a given concrete mix design, the preset period may be established from test data at various initial concrete temperatures. A minimum of three ASTM C403 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

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3. If necessary, the concrete temperature may be increased during the preset period at a rate not to exceed 10°F (5.6°C) per hour. The total permissible temperature gain during the preset period shall not exceed 40°F (22°C) higher than the placement temperature or 104°F (40°C), whichever is less.

When the concrete temperature is increased by more than 10°F (5.6°C) 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 “final curing” per ASTM C31, and specimens that receive “standard curing” in accordance with ASTM C31. 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.

4. For accelerated 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

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 half-hour.

Any changes in the concrete mix components that are likely to affect the preset time should be considered cause for performing new ASTM C403 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 (40°C) 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 concrete properties.

“Standard curing” requires that test specimens be stored for up to 48 hours at a temperature range of 60° to 80°F (16° to 27°C), followed by moist curing at a temperature of 73 ± 3°F (23 ± 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 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.

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with ASTM C403.

- 5. The maximum curing temperature shall not exceed 180°F (82°C). This temperature shall be measured at the portion of the unit that is likely to experience the maximum temperature during curing.
  
- 5. The maximum cooling rate from the sustained accelerated curing temperature shall be 50°F per hr (27.8°C per hr). In order to prevent surface crazing or other thermal related damage, the cooling at this rate shall continue until the concrete temperature is no more than 40°F (22°C) above the ambient temperature outside the curing enclosure or less.
  
- 7. Self-recording thermometers shall be provided to show the time-temperature relationship for the entire curing period or until stripping or transfer of prestress. At least one recording thermometer, per contiguous form group and common heat source, shall be used to monitor the product at appropriate locations.

- 4. The maximum concrete temperature should not be greater than that necessary to attain the minimum stripping and transfer strength in the required amount of time. If a known potential for alkali-silica reaction or delayed ettringite formation exists, the maximum curing temperature should be reduced to 158°F (70°C). Higher curing temperatures, and exposure to moisture while in service, can increase the potential for these types of deleterious reactions. Increases in cement fineness, SO<sub>3</sub>, and total equivalent alkali content above typical historical values, appear to be additional risk factors for such reactions.
  
- 6. Units should be allowed to cool gradually to prevent thermal shock, which may cause cracking. Additionally, when the concrete is warmer than the ambient conditions, there is a tendency for soluble salts (efflorescence) to migrate to the surface immediately after stripping.
  
- 7. To aid personnel who control the temperature during curing, it is recommended that the desired curing time-temperature relations 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. 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.

**4.19.2 Curing with Live Steam**

Steam curing shall be performed under a suitable 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, or test cylinders.

**C4.19.2 Curing with Live Steam**

Monitoring techniques will require temperature checks at various points to effectively control curing temperatures.

**Standard****Commentary****4.19.2 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.

**4.20 Curing by Moisture Retention Without Supplemental Heat****4.20.1 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 strength specified for transfer of prestress or stripping.

**4.20.2 Moisture Retention Enclosures**

Enclosures used for the purpose of retaining moisture during the curing period shall ensure that free water is present on all concrete surfaces at all times. Moisture retention enclosures shall be resistant to tearing and shall be positively fastened in place to avoid displacement by wind or other means during the curing cycle. Moisture retention enclosures shall remain in place until the completion of the curing cycle as described above.

**C4.19.3 Curing with Radiant Heat and Moisture**

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.

Radiant heat may be applied by circulating steam or hot liquids through pipes, electric blankets, heating elements, or by circulation of warm air. Heating devices should not be in direct contact with the concrete, forms, or test cylinders.

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 Article 4.19.

**C4.20 Curing by Moisture Retention Without Supplemental Heat****C4.20.1 General**

Acceptable methods of curing are:

- Leave the unit in the forms and keep the top surfaces continuously moist by fogging, spraying, or covering with wet mats, or by covering the top surface with an impermeable cover or membrane curing compound.
- Remove the side forms and cure all exposed surfaces by the applicable methods described above.

**C4.20.2 Moisture Retention Enclosures**

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**Commentary**

**4.20.3 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 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 re-coat areas of incomplete coating.
2. The membrane curing compound shall be applied to the exposed concrete surface at the minimum coverage rate recommended by the manufacturer.
3. The membrane curing compound shall be applied as soon as the surface bleed water sheen disappears.
4. The membrane curing compound shall be compatible with coatings or other materials to be applied to the product in later construction stages.

**4.21 Post-Tensioning Tendon Grout**

**4.21.1 Scope and Purpose**

Grout for post-tensioning tendons used in prestressed concrete members shall provide protection of post-tensioning steel and develop bond between the prestressing steel and the surrounding concrete.

**4.21.2 Materials for Post-Tensioning Tendon Grout**

The materials used for making grout to be used in post-tensioning systems shall meet the following minimum requirements:

1. Portland cement shall be in accordance with ASTM C150. The cement shall be Types I, II or III.
2. Water used in the grout shall be potable, clean, and free of materials known to be deleterious to cement or cause corrosion of the prestressing steel.

**C4.20.3 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.

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.

**C4.21 Post-Tensioning Tendon Grout**

**C4.21.1 Scope and Purpose**

Post-tensioning is sometimes used to supplement pretensioning in precast concrete units. It may be used to provide required prestress force in excess of stressing bed capacity, in construction of segmental elements, and in situations that require close control of camber.

**C4.21.2 Materials for Post-Tensioning Tendon Grout**

Type III cement is typically only used for cold weather grouting. When Type III cement is used, trial mixes should be performed to determine an appropriate mix design.

Admixtures may be used to reduce the water requirement and improve flowability at a given water content. While such admixtures are often used, research of horizontal tendons in semirigid ducts indicates that satisfactory grout quality may be achieved without admixtures.

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**Commentary**

3. Admixtures, if used, shall impart the properties of low water content, good flowability, minimum bleeding, and expansion, when required. Admixtures shall not contain chemicals in quantities that may be deleterious to the cement or cause corrosion of prestressing steel. Admixtures containing chloride ions (as Cl<sup>-</sup>) in excess of 0.5% by weight of the admixture, based on 1 lb (0.45 Kg) of admixture per 94 lbs (42.6 Kg) sack of cement, shall not be used. Admixtures that contain fluorides, sulfites, and nitrates shall not be used.

All admixtures shall be used in accordance with the manufacturer's recommendations.

**4.21.3 Proportioning of Grout**

Grout proportioning shall be based on tests made on trial mixtures, or may be selected on the basis of prior documented experience with similar materials, equipment, and under comparable field conditions (weather, temperature, tendon configuration, length, etc.).

The water content shall be the minimum necessary for proper placement. When Type I or Type II cement is used, the w/cm shall not exceed 0.45 by weight of materials.

The water content required for Type III cement shall be established on the basis of trial mixtures.

**4.21.4 Grout Mixing and Pumping Equipment**

1. The grouting equipment shall be capable of producing uniformly mixed grout that is free of lumps and undispersed cement. The equipment shall be able to continuously mix and pump the grout in a manner that will reliably and completely fill the tendon ducts.

A common international standard of practice for measuring the bleedwater of grouts is to use a metal or glass cylinder with an internal diameter of approximately 4 in. (100 mm) filled to a height of approximately 4 in. (100 mm) with grout. Recent research in the United States indicates that more representative test results may be achieved by using a grout specimen container with an internal diameter of approximately 1.25 in. (32 mm) filled to a height of approximately 20 in. (508 mm). The container should be covered during the test to prevent evaporation. The following are suggested limits for determining the acceptability of the grout:

1. The total bleedwater shall not exceed 2% by volume of the grout, measured 3 hr. after mixing.
2. Maximum total bleedwater shall not exceed 4% by volume of the grout.

An approved gas-evolving material that is well dispersed throughout the admixture may be used for obtaining 5% to 10% unrestrained expansion of the grout.

**C4.21.3 Proportioning of Grout**

Grout that is cured at a temperature of 65°F (18°C) and at a relative humidity of approximately 70% should produce a minimum compressive strength at 28 days of 4,000 psi (27.6 MPa), unless otherwise specified.

The water demand for Type III cement grout mixtures is generally more variable than for Type I or II cement mixtures. This is due to the increased variability in fineness of Type III cement.

**C4.21.4 Grout Mixing and Pumping Equipment**

A thixotropic grout undergoes significant changes in fluidity depending on whether the grout is in motion or quiescent. This property is caused by the use of additives.

Grouts developed with admixtures and other additives often develop thixotropic properties. Thixotropic grouts

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**Commentary**

2. Means for accurately measuring the mix constituents (batch quantities) shall be provided.
3. The grouting shall be performed with a positive displacement type pump that is capable of producing a minimum outlet pressure of 150 psi (1.05 MPa). The pump shall be properly sealed to prevent introduction of oil, air, or other foreign substance into the grout and to prevent loss of grout or water.
4. A pressure gauge having a full scale reading of no greater than 300 psi (2.10 MPa) shall be in the grout line between the pump outlet and the tendon duct inlet.
5. Grouting equipment shall contain a screen, with a maximum clear opening of 0.125 in. (3 mm) to screen the grout prior to pumping. This screen shall be easily accessible for inspection and cleaning.
6. The hopper of the grout pump shall be kept at least partially full of grout at all times during the pumping operation to prevent air from being drawn into the post tension duct.
7. Unless special conditions require special measures to be developed, the grouting equipment shall be capable of continuously grouting the largest tendon on the project within a maximum time of 20 minutes.

**4.21.5 Mixing of the Grout**

1. Water should be added to the mixer first, followed by the cement and admixture, unless otherwise required by the admixture manufacturer.
2. Mixing duration shall ensure a uniform, thoroughly blended grout, without excessive temperature increase or loss of expansive properties. The grout shall be continuously agitated until it is pumped.
3. Water shall not be added to grout that has lost fluidity due to a delay.
4. The pumpability of the grout shall be established by an approved method or on the basis of previous experience with the grout mix prior to grouting.

can undergo a significant loss of fluidity when mechanical mixing stops.

The grouting equipment should utilize gravity feed to the pump inlet from a hopper attached directly over top. This is a good way to ensure a continuous supply of grout to the pump.

Care should be taken to not overpressurize post-tensioning ducts, to ensure against damaging the surrounding concrete.

If a thixotropic grout is to be used, the screen opening size can be increased to 0.188 in. (5 mm).

Grout bleed tubes are generally used at tendon profile high points, to ensure that air is not trapped in these locations.

**C4.21.5 Mixing of the Grout**

Typical grout mixers for this type of application require 1.5 to 3 minutes to satisfactorily mix the grout.

The pumpability of the grout may be determined in accordance with the U.S. Corps of Engineers Methods CRD-C79. With this method, the efflux time after mixing should not be less than 11 seconds. The flow cone test does not apply to thixotropic grout.

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**4.21.6 Grout Temperature**

The temperature of grout should not be above 95°F (35°C) during mixing or pumping. If necessary to comply with the temperature limit, the mixing water shall be cooled.

**C4.21.6 Grout Temperature**

Difficulties in pumping grout may occur when the grout temperature in the mixer exceeds 90°F (32°C).

# DIVISION 4 - CONCRETE

## PROVISIONS FOR SPECIAL FINISHES

The following Articles, designated with an “A” prefix, apply to structural products with an architectural finish requirement. Conformance with the requirements of the Articles is required as part of certification in the Product Categories “Bridge Architectural” (BA), or “Commercial Architectural” (CA) within the Bridge Products and Commercial (Structural) Products Groups. For a description of these Groups, see Appendix F, *Certification Programs – Product Groups and Categories*.

The criteria established in this manual govern except as specifically modified by these provisions for the special class of products defined above.

The Article numbers are the same as the corresponding Articles in the main portion of the Standard. Where a special provision for architectural finishes does not have a matching Article in the main portion of the Standard, the provision is placed at the end of an Article or the Division with numbering continued sequentially.

### Standard

### Commentary

#### A4.1 Mix Proportioning

The mix shall be proportioned to ensure proper color and finish texture.

#### AC4.1 Mix Proportioning

Much of the skill, knowledge, and technique of producing quality architectural precast concrete depends on proper proportioning of the concrete mix. For example, surface finish requirements frequently will control the ratio of coarse to fine aggregate.

Concrete mixes for Category BA or CA elements are typically distinguished at the face or backup mix. Face mixes are usually composed of special decorative aggregates for exposed aggregate finishes and are frequently made with white or buff cement and/or pigments. Backup mixes are typically composed of more economical local aggregates and gray cement, which reduces the material costs in large units employing face mixes. Backup concrete mixes are also used where exposed aggregate or other special finishes are not required, and where the size and distribution of aggregate are not critical. In precast concrete units of complicated shapes and deep narrow sections, the face mix may be used throughout the member if procedures for separating the face and backup mixes become too cumbersome.

#### A4.1.1 Qualification of New Concrete Mixes

Evaluation of concrete mixes shall include all aesthetic requirements.

#### AC4.1.1 Qualification of New Concrete Mixes

An architectural precast concrete mix has demanding criteria, as appearance will be a governing criterion in addition to strength and durability. The dominant mix constituents that influence appearance are the proportions of fine and coarse aggregate, cement color,

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**Commentary**

and the use of pigments. Often, several types of aggregate must be blended. The blended properties of the mixture should be considered in proportioning the mix. Typically, the largest portion of the mix will be the coarse aggregate, which affects consistency, finishability, and strength. Careful selection of aggregate sizes, colors, and mix 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 mix design process.

**A4.1.2 Specified Concrete Strength**

**AC4.1.2 Specified Concrete Strength**

Architectural concrete mixes are generally proportioned for appearance, with strength considered secondarily. Because Categories BA and CA are for structural members, strength is a primary consideration, with aesthetics considered secondarily. However, when face mixes are used, the strength of the face mix is usually not critical to the performance of the product.

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 may be obtained by ensuring proper air entrainment and minimizing absorption limits.

**A4.1.4 Proportioning to Ensure Durability of Concrete**

**AC4.1.4 Proportioning to Ensure Durability of Concrete**

Aggregates subject to “pop-outs,” rusting, staining, or other surface deterioration should be avoided.

**A4.1.5 Compatibility of Face and Backup Mixes**

**AC4.1.5 Compatibility of Face and Backup Mixes**

To ensure compatibility between face and backup mixes, the following characteristics of each mix shall be assessed: (1) shrinkage; (2) thermal coefficient of expansion; and (3) modulus of elasticity.

Face and backup mixes should be proportioned to minimize variations in shrinkage, thermal coefficient of expansion, and modulus of elasticity such that the finished units meet the tolerance requirements for bowing and warping. To minimize the potential for compatibility concerns, such mixes should have similar water-cement and cement-aggregate ratios.

Special attention shall be given to mix compatibility when normal weight face mixes are combined with lightweight backup mixes.

The combination of a normal weight face mix and a backup mix 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

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**A4.1.6 Proportioning for Appearance of Concrete Surface**

The face mix for architectural concrete units shall be designed to produce the desired appearance taking into account the technique for obtaining the surface finish.

to verify satisfactory performance.

**AC4.1.6 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 mix. The material requirements will vary with the depth and amount of surface to be removed in exposed aggregate finishes. For shallow reveals, aggregate fines and cement significantly influence appearance. Deeper reveals are more significantly influenced by the coarse aggregate.

**A4.4 Proportioning for Concrete Workability**

In color-sensitive units, the slump shall be as low as possible and consistent between batches to ensure uniformity of color in the end product. Slump tolerances of  $\pm 1$  in. ( $\pm 25$  mm) prior to the addition of an HRWR shall be maintained for mix consistency and color control.

In general, where appearance and color uniformity are of prime importance, mixes may have considerably higher cement content than required for achieving the specified strength. If the cement is the main contributor to the color of the concrete, the color will intensify or darken as the cement content increases.

**AC4.4 Proportioning for Concrete Workability**

Concrete slump in color-sensitive architectural panels should not exceed 3 in. (75 mm), in most instances, prior to the addition of an HRWR.

**A4.7 Storage and Handling of Concrete Materials**

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.

**AC4.7 Storage and Handling of Concrete Materials**

Pigments are packaged in bags (dry powder pigments) and drums (liquid pigments).

**A4.14 Batching and Mixing Operations**

**A4.14.5 Batching of Admixtures**

Pigments shall be batched in a manner that ensures uniform distribution in the mix. Pigments shall be added with the cement.

Pigments shall be pre-weighed and batched from packages that are sized for a single batch.

**AC4.14 Batching and Mixing Operations**

**AC4.14.5 Batching of Admixtures**

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**Commentary**

**A4.16 Requirements for Transporting and Placing of Concrete**

**AC4.16 Requirements for Transporting and Placing of Concrete**

**A4.16.8 Placing Concrete in Wet and Rainy Conditions**

**AC4.16.8 Placing Concrete in Wet and Rainy Conditions**

The producer 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.

**A4.16.9 Placing Facing Concrete**

**AC4.16.9 Placing Facing Concrete**

When placing the initial concrete face mix, care shall be taken to avoid coating the reinforcement with cement paste that may affect proper bonding of the second stage of concrete. When this cannot be prevented, placing of the backup concrete mix shall be done prior to hardening of the coating, or it shall be cleaned off. Alternatively, the placement of the reinforcement shall follow the consolidation of the face mix.

Facing concrete shall be carefully placed and worked into all details of the form. 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. Each batch of concrete shall be carefully placed as closely as possible to its final position. Shifting during consolidation shall be minimized. Concrete shall only be spread with solid faced tools.

Members with intricate shapes and deep narrow sections generally require one uniform concrete mix 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 aesthetic joint between finishes. Multiple concrete face mixes with different colors generally should not be used within one unit unless an acceptable technique is used to prevent mixing of the two mixes. For example, a two-stage (sequential) non-monolithic casting method where one part of a unit is cast and allowed to harden or cure before the second state is cast.

Units with large or steep returns (such as channel column covers and some spandrels) may be cast in separate pieces to achieve a high quality finish on all exposed faces, and then joined with dry joints. Although the dry joint may not show with certain mixes and textures, a groove or quirk will help to mask the joint. Where desired, this joint can be recessed deep enough to allow installation of a small backer rod and placement of a 1/4 in. (6 mm) bead of joint sealant. Sometimes, precautions may be necessary to ensure water tightness of the dry joints. Care should be taken to ensure that the return is jugged and held securely at the proper angle during production of the base panel.

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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 form in such a manner that it may disturb the retarder. Concrete placement on a slope shall begin at the lower end and progress upwardly, thereby increasing compaction of the concrete.

The thickness of a face mix after consolidation shall be at least 1 in. (26 mm) or a minimum of 1-1/2 times the maximum size of the coarse aggregate, whichever is larger. A face mix shall be thick enough to prevent backup concrete from showing on the exposed face.

**A4.16.10 Placing Backup Concrete**

When placing backup concrete, care shall be taken to ensure that it does not displace the face mix.

**A4.17 Consolidation of Concrete**

**A4.17.7 Consolidation of Face and Backup Mixes**

Special attention is required for consolidation of face mixes, especially if the aggregates are to be exposed later by removing the paste from the surface.

Layers of the face mix concrete shall be placed as level as possible so that the vibrator does not need to move the concrete laterally. Lateral movement may cause segregation. Mounds or high spots in the surface of the concrete shall be leveled by hand or with a mechanical screed.

**A4.18 Requirements for Curing Concrete**

**A4.18.1 General**

To produce concrete of uniform appearance, consistent and uniform curing conditions shall be provided.

The 1 in. (25mm) minimum thickness of the face mix dimension is chosen because the consolidated face is normally used to provide the proper concrete cover over the reinforcement. For units not exposed to weather or for face mixes applied face-up, this dimension may be reduced to 3/4 in. (20 mm) provided the backup mix does not bleed through.

**AC4.16.10 Placing Backup Concrete**

The allowable time interval between placing the face mix and backup is dependent on the concrete mix characteristics and environmental conditions.

**AC4.17 Consolidation of Concrete**

**AC4.17.7 Consolidation of Face and Backup Mixes**

**AC4.18 Requirements for Curing Concrete**

**AC4.18.1 General**

# **DIVISION 5 - REINFORCEMENT AND PRESTRESSING**

## **Standard**

## **Commentary**

### **5.1 Reinforcing Steel**

### **C5.1 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 frequently 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**

The 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 on blocks, racks, or sills, off the ground. 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 subdivided 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 of 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.

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 sags in 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.

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.

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Each bundle of welded wire reinforcement shall have a suitable tag attached 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.

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 linear 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 A775/A775M and in accordance with patching material manufacturer's recommendations.

**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 and with severity and rate of bending.

Local removal of the galvanized coating in the area of welds, bends, or sheared ends will not significantly affect the protection offered by galvanizing, provided the exposed surface area is small compared to the adjacent surface area of galvanized steel. When the exposed area is excessive, and gaps are evident in the galvanized coating, the area should be repaired.

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When epoxy-coated reinforcing bars are welded or cut during fabrication, the weld area and the ends of the bars shall be coated with the same material used for repair of coating damage.

The starting and ending points of a welded wire reinforcement bend with an inside diameter less than 8 wire diameters shall be located at least 4 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 4 wire diameters. A minimum of 2 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 sub-assemblies, shall be constructed to fit in the forms without being forced. Cages shall have sufficient three-dimensional stability so that lifting from the jig and placing into the form can be performed without permanent distortion. Also, the reinforcing cages shall be sufficiently rigid to prevent dislocation during the 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 with the approval of the precast engineer. Zinc-coated reinforcement shall be tied with zinc-coated annealed tie wire, non-metallic coated tie wire, soft stainless steel, or other acceptable materials. 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.

**Standard****Commentary**

All splicing of welded wire reinforcement or reinforcing bars, whether by lapping, mechanical connections, or by welding, shall be shown on the approved shop drawings. The concrete cover and bar spacing, 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 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.

If there is 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 forms 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 effects.

Zinc-coated (galvanized) reinforcement supported from the form shall rest on bar supports made of 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.

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**

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.

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Epoxy-coated reinforcing bars supported from the form 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 non-conductive 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 reinforcement exceeding allowable tolerances shall be corrected. The horizontal clear distance between reinforcement and form shall be equal to the specified concrete cover or 1.5 times 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.

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 shall provide adequate protection. Low permeability is characteristic of well-consolidated concrete with a low water-cementitious material ratio and high cement content.

For concrete surfaces exposed to weather, prestressing strand should be protected by a minimum concrete cover of 1 in. (25 mm). Reinforcing steel should be protected by concrete cover equal to the nominal diameter of bars but not less than 3/4 in. (19 mm).

For members not exposed to weather, ground, or water, the prestressing strand should be protected by a minimum concrete cover of 3/4 in. (19 mm). Reinforcing steel should be protected by a concrete cover not less than the nominal diameter of bars, but not less than 5/8 in. (16 mm).

Cover requirements over reinforcement should be increased to 1-1/2 in. (38 mm) for non-galvanized reinforcement or to 3/4 in. (19 mm) for galvanized or epoxy-coated reinforcement, when the precast concrete elements are exposed to a corrosive environment or to severe exposure conditions. However, the 3/4 in. (19 mm) 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.

**Standard****Commentary**

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 tolerance specified. 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 prestressing steel be eliminated to accommodate hardware.

**5.2 Tensioning****5.2.1 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

Reinforcing bar sizes No. 3 through No. 5 may be cold bent the first time, provided the reinforcing bar temperature is above 32 F (0 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 5 bar diameters in each direction from the center of the bend 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°F. (260°C). The preheat temperature of the reinforcing bar should be between 1100° to 1200°F (593° to 649°C). The preheat temperature should be maintained until bending or straightening is complete. The preheat temperature should be measured by temperature measurement crayons, contact pyrometer, 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°F (316°C).

**C5.2 Tensioning****C5.2.1 General Tensioning Requirements**

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

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**Commentary**

prestress force is critical for both performance and structural safety and it cannot be checked accurately later in the production process, tensioning operations shall be subject to careful production and quality controls.

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 measuring 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 algebraically agree with each other within 5%. If the measurements do not agree 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 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 the correct size of tendon has been used and operational losses are within tolerance limits, and it 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 Article 5.3.11 and for information on force corrections refer to Article 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 specification 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, as necessary to eliminate slack in the system, shall first be applied. After an initial force has been applied to the tendon, reference points for measuring elongation due to additional tensioning forces shall be established.

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.

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.

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.

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**5.2.3 Methods of Force Measurement**

Methods of measurement of the tensioning force shall consist of one or more of the following:

1. Pressure gauges to measure force from the pressure applied to hydraulic jacks.
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 element.
4. Digital readouts connected to a pressure transducer to measure force from the pressure applied to the hydraulic jack.
5. Force computed from the actual elongation of the strand 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 tolerance of  $\pm 2\%$  of anticipated loads. Gauges, jacks, pumps, hoses, and

**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 shall 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.
4. See commentary for item number 1.
5. 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, chuck-to-chuck.

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

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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, calibration service, or under the supervision of a registered professional engineer 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 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 measurement 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, unless the gauge/transducer is calibrated in that range with a verified 2% accuracy.

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 jacking 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

cells placed on either side of the movable end carriage.

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.

**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 which 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

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ineffective if a wire breaks in a 3-wire strand.

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.

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.

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.

**5.2.7 Calibration Records for Jacking Equipment**

**C5.2.7 Calibration Records for Jacking Equipment**

Calibration records shall show the following data:

1. Date of calibration.
2. Agency, laboratory or registered engineer supervising the calibration.
3. Method of calibration; i.e., 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).

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 calibration data. Accordingly, such data should be distributed to personnel preparing tensioning calculations.

Tensioning system calibration may be performed by properly supervised plant personnel.

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**

**C5.3 Pretensioning**

**5.3.1 Storage of Prestressing Steel**

**C5.3.1 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. 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. Special attention shall be given to protecting sheathing when unloading and storing coiled, sheathed-tendons. Prestressing steel shall be stored off the ground.

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.

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Care shall be taken in the storage of prestressing steel to prevent corrosion due to humidity, galvanic or battery action.

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, which deeply etches or pits the surfaces, cannot be tolerated on prestressing steels; however, a light coating of tight surface rust is beneficial to bond.

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.

Strand properties are altered by concentrated heat or arcing electrical current. This alteration can result in lowered ultimate strength and strand failure when placed under load.

**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.

**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.

Each plant shall develop written tensioning procedures providing step-by-step instruction for 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 final 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 or measurements.
9. Detensioning and stripping.

**Standard****Commentary****5.3.3 Strand Surfaces**

Special care shall be exercised to prevent contamination of strands from form release agent, mud, grease, or other contaminants that would reduce the bond between the steel and concrete. Form release agent shall be applied to the form 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 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 release agent or other surface coatings and, if contaminated, shall be cleaned using an approved method.

**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 clean 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 assure release without excess or puddles that may contaminate strand placed in the form. Excessive release agent should be removed from the form surface.

**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, reel-less packs, or on reels. Strands may be strung individually or in multiples. Strand paid-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 operation.

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 which may result in failure of the strand during tensioning. Such damage may also lower the ultimate strength of the strand through fatigue.

**Standard****Commentary****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, distorted, or which 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; i.e., 1/2 in. (13 mm) barrels with 7/16 in. (11 mm) wedges, etc.

**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.

For multiple-strand tensioning, either all or none of the strands may be spliced. If splices are used, there shall be an equal number of splices in each strand of the setup.

**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 which 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 assure 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 reseated.

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**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 and Appendix B.

**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 intermediate bulkheads along the form. Member behavior is relatively insensitive to horizontal location of tendons in typical flat panels or members significantly wider than 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 is especially critical and should be closely controlled and monitored. The sequence of placement and location of reinforcing steel, inserts, and block-outs should be carefully planned to avoid interference with the designed vertical position of the prestressing steel.

**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.

**C5.3.8 Spacing of Strands**

Half-inch “special” strand is larger than normal ½-in. strand. Similar spacing should be used. A larger spacing is not necessary. Half-inch “special” strand is at the upper limit of the ASTM requirement for ½-inch nominal strand..

**Table 5.3.8 Minimum Spacing of Strand**

<b>Strand Size, in. (mm)</b>	<b>Spacing, in. (mm)</b>
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)

To increase the efficiency of strands by increased eccentricity of the tensioning force at points of maximum flexure (usually at the center of the member) strands may be harped and bundled (placed immediately adjacent to each other) provided they are adequately splayed at the ends of the member to provide for development and distribution of the bonding force. Splaying between the point of bundling and the ends of the member shall be in straight lines

Bundling of strands has proven to be a major design benefit for prestressed concrete. However, without proper splaying, the strand will not develop ultimate strength.

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over minimum development lengths as determined in applicable codes.

**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 between 5 and 25% of the final force shall be applied to each strand. Regardless of the method used, the initial force shall be measured within a tolerance of  $\pm 100$  lb ( $\pm 45.4$  kg) per strand if the initial force is 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, care shall be taken to tension strand symmetrically to prevent warping of the form due to eccentric loading.

**5.3.10 Measurement of Elongation**

At the completion of initial tensioning, reference marks shall be established for which elongation by final tensioning can be measured. Elongations shall be accurately measured from the reference points as required in Articles 5.2.2 and 5.3.13.

**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 force of less than  $0.40 f_{pu}$  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.

For multiple strand setups, elongation can be measured by the travel of the tensioning header. Both approaches should be monitored to confirm operational losses and adjustments. The operational corrections considered in the measurement of elongation are outlined in Article 5.3.11 and should be included in each setup.

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. (13 mm) diameter high tensile strength strand and wire, accuracy of 1/4 in. (6 mm) corresponds to force variations of approximately 3% in a 50 ft (15 m) length of bed or member and 1% for a 150 ft (46 m) bed or member. Accuracy of this order can and should be attained.

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**5.3.11 Elongation Calculation and Corrections**

The elongation measurement shall account for all operational 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 in article 5.2.2. 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.**
  - a. Dead end seating.** 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. Live end seating.**
  
  - c. Splice chuck seating.**
  
- 2. Friction in the jacking system.**

**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 should be surveyed and monitored to establish appropriate elongation corrections. Any alterations of the form will require reevaluation of corrections and many new setups will require variation in assumptions. The following are the most common corrections for consideration:

- 1. Chuck seating.**
  - a. Dead end seating** – 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. Live end seating** – 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 1/4 in. to 3/4 in. (10 to 19 mm). This should be monitored by plant personnel to determine an appropriate value for the tensioning system in use at the plant.
  
  - c. Splice chuck seating** – Similar to dead end seating loss, the strands are predominately 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.
  
- 2. Friction in the jacking system.**

Elongation corrections are not required for friction compensation. Refer to Article 5.3.12 for applicable force corrections.

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**3. Form shortening (self-stressing forms).**  
Self-stressing forms take on the force of the tensioned strand as a compressive load, which shortens the bed.

**3. Form shortening (self-stressing forms).**  
Self-stressing forms will shorten under load. Since elongation is typically measured as a reference to the end of the form, the form shortening shows up as increased elongation. As one single strand is tensioned, the form shortening is very slight. However, members do not move instantaneously under load, and the form is no exception. Many times the form has enough friction on the subsurface to restrain movement until a given point. That is why an average value is best used, since there is no way to predict when shortening will take place.

**4. Abutment rotation or movement of anchorages.**

**4. Abutment rotation or movement of anchorages.**  
This is most commonly a phenomenon for fixed abutment forms where the loads are imposed onto the abutments, which deflect elastically. The foundation has potential movement as well. The movements are usually very small for well-constructed abutments, but they should be evaluated and compensated for in calculations.

**5. Thermal effects.**

**5. Thermal effects.**  
In the event that thermal changes are anticipated, such as when the strand is warmed from a cold morning tensioning to concrete placement, then the calculated elongation must be changed to correspond to the changes in stress.

**6. Other corrections.**

**6. Other corrections**  
This includes compensation for certain methods of tensioning harped strands. This may be required due to changes in strand length resulting from lifting or depressing.

**5.3.12 Force Corrections**

**C5.3.12 Force 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 compensation 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. Multiple-strand tensioning methods, because of the large jacking ram and the heavy sliding or rolling anchorage to which all strands are attached, are subject to friction

- 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 over-pull.
- 2. Friction in jacking system.**
  - a. Instances where 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

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which must be overcome by the jack. This force is in addition to the force required to tension the strand. There may be substantial variations in friction between various strand patterns. To minimize friction, the sliding surfaces shall be clean and well lubricated. If two methods of force measurement exceed the allowable variation, a third method shall be used.

tensioning force.

- b. 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 Article 5.2.7. The anchorages are not part of the jacking system.
- c. Losses in the tensioning system shall be compensated for in accordance with Article 5.2.4
- d. 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 specified load.

- c. Internal friction in gauges, jacks, pumps, hoses, and connections is accounted for when the entire system is calibrated as a unit.
- d. 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 process, strand liftoff to check gauge pressure may be necessary.

**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.

**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. Adjustment 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.**

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 outside of the 5% tolerance, then an adjustment is required.

**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 shortening, are necessary.

**Standard**

**Commentary**

**5. Thermal effects.**

For abutment anchorage set-ups where strands are anchored to abutments that are independent from the form, thermal adjustments shall be made if the temperature of the steel at the time of tensioning differs by more than 25°F (15°C) from the time the concrete begins to set and if the net force differential is greater than 2-1/2%. 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  $6.5 \times 10^{-6}/^{\circ}\text{F}$  ( $12 \times 10^{-6}/^{\circ}\text{C}$ ).

**6. Gauge correction based on calibration data.**

**7. Other corrections.**

**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 at mid-day or afternoon. The actions would be reversed for strands 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 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 (5°C) 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 correction 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.

**7. Other corrections.**

This includes compensation for certain methods of tensioning harped strands. This may be appropriate where friction between the last point of deflection and the jack affects the agreement between elongation and gauge pressure but not the tension of the strand in the product. The stress limits for strand still apply in this case, and, if stress cannot be held below the limit, friction points must be removed from the setup.

**Standard**

**Commentary**

**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 Article 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.

For multiple-strand tensioning, following application of initial force and seating of each strand on the anchorage header, reference marks shall be established for measuring elongation and seating. Reference marks for seating shall be made by marking a straight line across the strands in each row and along the face of the anchorage. For uniform application of force to strands, the face of anchorage at final load shall be in a plane parallel to its position under initial force. Parallel movement shall be verified by measurement of movement on opposite sides of the anchorage and a check of its plumb position before and after application of the final force.

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**

Harped pretensioning strands may be finally tensioned by either of the following:

- 1. Partial tensioning and subsequent strains.**  
In this method, the strands are tensioned in a straight position or on a partially harped trajectory, to a pre-determined intermediate force value between initial and final force. The final force is induced by strains resulting from lifting or depressing strands at all other points of change in strand alignment. Final position and force shall be offset symmetrically about the center of the setup to distribute friction evenly. Force and elongation shall be measured as specified in Article 5.2.2 for the intermediate force value. Suitable force measurements at each anchorage at each end of the bed shall verify calculated strand forces within 5%. This verification shall be made prior to first casting for any new design or new strand pattern, or with new bed equipment; thereafter, periodic checks are recommended.

**C5.3.13 Final Tensioning of Straight Strands**

Straight strands are the most straightforward tensioning setup. Care is required to be sure 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**

- 1. Partial tensioning and subsequent strains.**  
This method requires a carefully predetermined layout of members on the bed and definite positions of lifting and hold-down devices in order to compute the changes in the length of the strand caused by placing strand into the final harped position. This method can be used with either single strand or multiple strand tensioning.

The strand over most of the bed length will be tensioned to the intermediate value in either a low position or a high position. When tensioned in the low position, the strand is held down at low points within the member and lifted between members. When tensioned in a high position, the strand is held up between members and forced down at points within the member.

**Standard**

**Commentary**

**2. Final tensioning in harped position.**

In this method, the strands are tensioned to final value in the harped position for the full length of the bed. The strands shall pass over devices, which effectively minimize friction at all deflection points. Force and elongation shall be measured as specified in Article 5.2.2.

When final tensioning is done by jacking strands from one end of the bed, even when that tensioning is within tolerance, force shall be measured on at least two strands at the far end. This force shall not be below the theoretical values by more than 5%. If the theoretical elongation has not been attained at one end of the bed when the force, as indicated by pressure gauge or load cell, is exceeded by 5%, the strand shall be jacked from the other end of the bed to the theoretical elongation. If this requires an overstress as indicated by the gauge in excess of 5% overload, the number of deflection points on the bed shall be reduced until the elongation can be attained with not more than 5% overload or the hardware shall be improved to reduce friction. Remaining deflection points shall then be achieved as outlined in Article 5.3.14(1).

If elongation is not obtained within 5% tolerance when theoretical force has been applied, the force may be temporarily increased to overcome friction. Provisions shall be made to reduce the force on the strand to within 5% of the theoretical force, not to exceed 80% of the specified tensile strength of the strand, at final seating.

To distribute friction and any restraint at lifting and hold-down devices, the ideal method is to lift or depress simultaneously at all points on the bed. If this is impractical, the lifting or depressing shall commence at the point nearest the center of the bed, and then progress alternately at points equidistant from the center to the ends of the bed.

**2. Final tensioning in the harped position.**

Support and hold-down devices should be of sufficient rigidity and have adequate support so that the position of strand will remain substantially unchanged under the induced forces in this method.

Procedures should be established to minimize friction at both high and low control points of the strand. The use of pin and roller assemblies generally provides the best method of reducing friction at hold-up and hold-down points. Extra caution should be observed in tensioning harped strands to avoid undue exposure to safety risks of the personnel involved.

**Standard**

**Commentary**

**5.3.15 Equal Distribution of Force in Harped Strands**

Distribution of force in strands throughout the length of a bed can be determined by measuring elongation of a predetermined length of strand in each member. This procedure shall be employed for the initial setup of a newly installed bed if the bed differs substantially from other beds at the plant or if harping hardware or procedures differ from those normally used.

**C5.3.15 Equal Distribution of Force in Harped Strands**

Friction at each of the deflecting devices resists some of the force exerted in tensioning harped strands. The force applied to the strand is therefore decreased at each successive point of deflection away from the source of jacking. For this reason, this procedure is to be used when a new casting facility is first installed if it differs substantially from those already in use. For example, a new bridge beam bed to make Type IV beams should be evaluated when first set-up if it is the first of its kind at the plant. If the plant has already been manufacturing Type III beams with the same or similar harping hardware and procedures, the new bed can be considered additional capacity of similar products and not substantially different. Force distribution should be checked when tensioning procedures change. An example is when strands were previously tensioned straight and subsequently harped and the procedure changes to tensioning in the final fully harped position.

This procedure is not intended to apply to regular, routine changes in form configuration or product layout within the bed.

Measurements of strand elongation at locations within the element are difficult to perform. Form, reinforcing, and equipment restrict access. Evaluation of a measuring tape or bar cannot be considered reliable if read closer than to the nearest one eighth of an inch. The tolerance between measured and calculated elongation should be 5% rounded up to the nearest 1/8 in. For example, if the desired elongation of a 20-ft section of strand is 1-1/2 in., then the acceptable range of measurements should be from 1-3/8 in. to 1-5/8 in. ( $\pm 1/8$  in.). This is because 5% of 1-1/2 in. is 0.075 in. Rounding up to the nearest eighth results in a value of 1/8 in. Measuring bars or tapes should be maintained at or near the temperature of the strand to eliminate thermal differences in measurements. It must be noted that this procedure has significant inherent safety risks due to the necessity of having to work in direct contact with tensioned and harped strand. Therefore, it should be accomplished only when considered necessary as required above. Great care must be exercised and appropriate safeguards applied.

**Standard****Commentary****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 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, ties, inserts, or other devices that restrict longitudinal movement of the members along the bed shall be removed or loosened. Alternately, detensioning shall be performed in such a manner and sequence that longitudinal movement is precluded.

In multiple-strand detensioning, strands are released simultaneously by hydraulic jacks. The total force is taken from the header by the jack, then released gradually. The over-pull required to loosen lock nuts or other anchoring devices at the header shall not exceed the force in the strand by more than 5%.

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

**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 portions of the member. Leakage of paste into sleeving must be 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 utilized.

**C5.3.17 Detensioning**

Tests have shown that the bond transfer length for wet mix concrete is not appreciably affected by concrete strengths in the range of 2,500 psi to 4,000 psi (17.2 to 27.6 MPa) at release. Concrete strength does influence camber and dimensional changes due to strains in the concrete. A minimum concrete transfer strength of 3000 psi (20.7 MPa) is recommended.

If concrete is allowed to dry and cool after steam curing and prior to detensioning, dimensional changes may cause contraction cracking or undesirable stresses in the concrete. Strands should be detensioned immediately upon stripping off covers, or a way should be developed to detension strands before stripping the covers (or partially detensioned before stripping covers). 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 the area of member

**Standard**

**Commentary**

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 shall be limited to one strand or 10% of the strand group. Vertical axis eccentricity shall be limited at initial cutting of the ends of the bed and as strands are cut between members in setup. Detensioning shall be performed in a manner that will minimize sudden shock or loading.

increases.

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.

**5.3.18 Detensioning of Harped Strand**

**C5.3.18 Detensioning of Harped Strand**

Hold-down forces shall always be computed and compared with the weight of the member if hold-downs are to be released prior to release of the strands from the anchorage.

For members having harped strands it is particularly important that no longitudinal movement be allowed along the beds until the hold-down devices are removed, as any such movement may cause serious cracking of concrete or destruction of the hold-down devices or both. It is therefore advisable to release hold-downs and remove bolts prior to releasing the forces at the anchorages; however, release of hold-downs without release of anchorage force may result in dangerous concentrated vertical loads that can crack the top of the member. In general, if the sum of hold-down forces is not more than half the weight of the member, it is safe to release hold-downs prior to release of the anchored force. If the hold-down forces are less than three-quarters of the weight of the member and nominal reinforcing steel is carried in the top flange or slab, cracking is unlikely. If the hold-down forces approach the weight of the member and if hold-downs are released prior to the anchorages, some cracking is inevitable in the upper surfaces immediately above the hold-downs. Sizing of reinforcing steel for this is addressed in ACI 318.

The effect of vertical forces resulting from initial release of hold-downs can be minimized by weights or vertical restraint applied over the hold-down points.

Cracks resulting from initial release of hold-downs will generally close upon release of the anchorage force. No rules regarding the sequence of hold-down and anchorage forces can be given as the incidence of upper surface cracking will vary with the size and shape of the member, concrete strength, and the amount of reinforcing steel in the upper region of the member.

Detensioning of heavily stressed sections should be done at all points between members simultaneously to avoid damage caused by product movement or shock. Heavily stressed sections with harped strand may require a partial

**Standard**

**Commentary**

release of harped strand at the end of the member before releasing hold-downs to avoid top fiber cracking.

**5.3.19 Detensioning of Dry-Mix, Machine-Cast Products**

Each plant shall have a program to determine and evaluate strand slippage.

**C5.3.19 Detensioning of Dry-Mix, Machine-Cast Products**

In dry-mix, machine-cast products, achieving good bond between the concrete and the prestressing steel is primarily a function of the degree of consolidation of the concrete. Inconsistencies in the concrete mix or mechanical malfunction in the equipment may also lead to bond failure. When this occurs, strand slippage may be evident and the product shall either be rejected or its performance evaluated on the basis of some loss of bond. Detensioning slippage must be monitored beginning at a solid section of concrete. After concrete placement is finished, it is necessary to clean the last trailoff or beginnings of the concrete placement away from the strand to allow the mark for measurement of slippage to be made on the strand directly adjacent to a solid section of the product. The mark on the strand should preferably be placed approximately one foot from the solid section of slab. A standard grillage should be used to make the mark on the strand during the operation each day and set beside the bed. This grillage can then be used to evaluate the slippage as well as making the marks. If the mark is made excessively far from the end of the product, then the mark will move due to the movement of the strand as it is detensioned between the point of the mark and the end of the product. For this reason, placing the mark close to the end is preferable.

Evaluation of slippage is imperative. The loss of prestress is particularly hazardous for dry-mix products since shear capacity is chiefly provided by the prestress force. A lack of shear capacity creates a potentially dangerous situation of member failure, possibly with no prior warning.

Loss of prestress due to slippage also reduces load-carrying capacity since the moment capacity reduces as the slippage increases. The affected length of slipped strand is determined by considering an overlap of the zone of flexural bond with the zone of strand stress development bond.

**5.3.20 Protection of Strand Ends and Anchorages**

Special attention shall be directed towards finishing the ends of 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

**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.

**Standard****Commentary**

anchorages shall be protected against moisture penetration.

Under such circumstances, adequate protection may be mandatory.

When exposed to view, anchorages (stressing pockets) should be recessed and packed with a minimum of a 1-in. (25 mm) thickness of non-metallic, non-shrink mortar and receive a sack finish. Prior to installing the pocket mortar, the inside concrete surfaces of the pocket should be 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.

**5.4 Post-Tensioning of Plant-Produced Products****C5.4 Post-Tensioning of Plant-Produced Products****5.4.1 General****C5.4.1 General**

The tensioning of post-tensioned members is governed by many of the considerations applicable to pretensioned concrete.

The process of post-tensioning incorporates the installation of either 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 anchored against the hardened concrete.

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 to 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.

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 paper or plastic. Unbonded tendons are connected to the member only through the anchorage hardware, which should be sized and designed in accordance with ACI 318.

Records shall be maintained for plant post-tensioning operations in a similar fashion to other plant operations.

**Standard**

**Commentary**

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.

**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/polypropylene tubing installed within the member. Tendons, which 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 foot 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

Anchorages and pocket formers should be rigidly attached to the forms 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 deformations (indentations) in the sheathing.

**C5.4.2 Details and Positions for Ducts**

Materials commonly used for formed ducts are 22 to 28-gauge galvanized, bright spirally wound, or longitudinally seamed steel strip, with flexible or semirigid 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 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.

**Standard****Commentary**

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 forms shall be sufficiently supported and fastened to ensure 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 placing the ducts, reinforcement, and forms, 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 to either 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 over-jacking, jacking from both ends, and over-elongation 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.

Tendons may be installed in the ducts either prior to or subsequent to placing concrete. In general, it is 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.

**Standard**

**Commentary**

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 manufacturers' recommended procedure.

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.

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  $0.70 f_{pu}$ .

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, 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.

**5.4.5 Anchorages**

**C5.4.5 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.

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.

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 strand are post-tensioned. Minimum concrete cover for the anchorage shall not be less than the minimum cover to the reinforcement at other locations.

Plastic pocket formers used as a void form at tensioning anchorages shall prevent intrusion of concrete or cement paste into the wedge cavity during concrete placement. Pocket formers shall be coated with grease prior to insertion to help prevent concrete leakage into the anchorage and to aid in removal during form stripping.

**Standard****Commentary****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 vents are closed, pumping shall continue until a steady pressure of 100 psi is maintained for 10 seconds.

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.

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, which will provide fire resistance at least equal to that required for the structure.

**C5.4.6 Grouting**

Post-tensioning members which are to carry heavy fluctuating or dynamic loads or which 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, an approved rust inhibitor can be applied to the tendon before placement in the duct.

**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 5 – REINFORCEMENT AND PRESTRESSING***

## ***PROVISIONS FOR SPECIAL FINISHES***

The following Articles, designated with an “A” prefix, apply to structural products with an architectural finish requirement. Conformance with the requirements of the Articles is required as part of certification in the Product Categories “Bridge Architectural” (BA), or “Commercial Architectural” (CA) within the Bridge Products and Commercial (Structural) Products Groups. For a description of these Groups, see Appendix F, *Certification Programs – Product Groups and Categories*.

The criteria established in this manual govern except as specifically modified by these provisions for the special class of products defined above.

The Article numbers are the same as the corresponding Articles in the main portion of the Standard. Where a special provision for architectural finishes does not have a matching Article in the main portion of the Standard, the provision is placed at the end of an Article or the Division with numbering continued sequentially.

### **Standard**

### **Commentary**

#### **A5.1 Reinforcing Steel**

#### **AC5.1 Reinforcing Steel**

##### **A5.1.4 Installation of Reinforcing Steel**

##### **AC5.1.4 Installation of Reinforcing Steel**

If possible, reinforcement cages shall be securely suspended from the back of the forms.

Consistent with the structural requirements of the element, reinforcement should be placed as symmetrically as possible about the cross-sectional centroid of the unit to minimize bowing and distortion. Nonsymmetrical placement may cause warpage due to restraint of drying shrinkage or temperature movements.

For exposed aggregate surfaces, the concrete cover to surface of steel shall be measured from the form surface and the typical depth of mortar removal between the pieces of coarse aggregate shall be subtracted. Attention shall also be given to scoring, false joints, rustications, and drips. The required minimum cover shall be measured from the thinnest location to the reinforcement.

Reinforcement shall be placed within the allowable tolerances, but the concrete cover shall never be less than the specified cover. 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 absence of surface rust staining.

Spacers (bar supports) or chairs may mar the finished surface of an element which will eventually be exposed to weathering.

**Standard**

**Commentary**

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# 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.

Pre-pour and post-pour inspections are useful for managing quality. Recurring defects require decisive corrective action by management.

Every effort towards cooperation shall be observed between production personnel, who are responsible for quantity and quality, and inspection personnel, who are responsible for observing and monitoring 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 pre-pour inspection, and each type of element (different mark numbers) may have a different set of requirements. A plant's training program should include a definitive outline of items to be inspected.

#### 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 the testing of materials, tensioning, concrete proportioning, placing, curing, inspection of finished products, camber, member dimensions, and concrete strength.

To document the pre-pour inspection, quality control records should be identified with the same job number, mark number, and other information used to identify the product after inspection.

In general, the scope of quality control pre-pour and post-pour inspections to be performed in precast concrete plants shall include, but not necessarily be limited to, the following:

The post-pour inspection is frequently the last and sometimes the only opportunity to confirm that products were made in conformance with the shop drawings. The most important aspect of the post-pour inspection is the timeliness of the inspection. Post-pour inspections should be made as soon as practical after products are stripped from their forms. If a defect is evident, or a mistake has been made, and that defect or mistake is detected during the post-pour inspection, similar defects and/or mistakes in products yet to be cast can be prevented.

1. All required plant testing and inspection of materials and embeds for acceptance prior to initial concrete placement and daily check testing for quality maintenance.
2. Mix design for all concrete and required ingredients for concrete testing.
3. Inspection of forms and new setup changes prior to placement of concrete. The plant shall prepare its own list of items to be checked as part of the pre-pour inspection, and emphasis shall be on items that cannot

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

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**Commentary**

4. readily be checked after concrete placement. Checking of blockout position, cast-in items, position and amount of reinforcement, and any other critical tolerance items. This also includes verifying these items are properly secured during placement of concrete.
5. Check forms and appurtenances for adequate maintenance by verification of tightness, dimensions, and overall general quality.
6. Daily detailed inspection of batching, mixing, conveying, placing, compacting, curing, and finishing of concrete.
7. Daily inspection of stripping product from the forms.
8. General observation of plant, equipment, weather, and other items affecting production.
9. Preparation of concrete specimens for testing and performing slump, air content, compressive strength, and other concrete tests.
10. Inspection of finish to ensure that the product matches the standard established by the plant and client. Finish defects, cracking, and other problems shall be reported and a decision made as to acceptance, repairs, or required manufacturing changes. Products that are damaged are to be recorded, marked, and reinspected after being repaired.
11. Check finished product against approved shop drawings and plant standards to 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. Check initial camber on at least 25% of each day's production within 72 hours after transfer of prestress force.
13. General observations of storage area for proper blocking, methods for prevention of chipping, warping, cracking, contamination, and blocking stains, or any other items that may adversely affect the quality of the product.
14. Final inspection of product during loading for proper blocking and observation of problems such as chips, cracks, warpage, or other defects.
15. Inspection of products following any repair.
16. Disposition of nonconforming products.

inspections and tests. Assignments and responsibilities for all inspecting functions should be clearly defined 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**

**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 the precast concrete unit shall follow plant standards as well as standards required by the specifications for a particular project.

Testing is necessary for internal plant quality control as well as quality control of the precast concrete unit. 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 quality control 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.

For control of concrete, testing of specimens, and design and control of concrete mixes, each precast concrete plant shall be equipped with adequate testing equipment and staffed with personnel trained in its proper use.

Specified properties of all materials in Divisions 3 and 4 shall be verified by appropriate ASTM standard tests either performed by the material supplier or the precast concrete plant.

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 full information on material tests, mix designs, concrete tests, and any other necessary information.

**6.2.2 Acceptance Testing of Materials**

**C6.2.2 Acceptance Testing of Materials**

Suppliers of materials shall be required to furnish certified test reports for cement, aggregates, admixtures, curing materials, reinforcing and prestressing steel, and hardware materials, indicating that these materials comply with the applicable ASTM standards, project specifications, and plant standards.

In some instances, materials may not conform to nationally recognized specifications but may have a long history of satisfactory performance. Such nonconforming materials are permitted when acceptable evidence of satisfactory performance is provided and approved by the architect/engineer.

**Standard**

**Commentary**

**1. Cement.**

If mill certificates are not supplied, representative testing of each shipment of cement is required before use. The mill certificate shall contain the alkali content in percent expressed as Na<sub>2</sub>O equivalent. Mill certificates or test reports of cement shall be kept on file in the plant for at least five years after use. Characteristics of special cements not conforming to ASTM C150 shall be investigated prior to use to be certain that they do not exhibit undesirable attributes of high slump loss, strength retrogression, plateau strength, or other aberrations under typical casting and curing conditions.

**2. Aggregates.**

Fine and coarse aggregates shall be regarded as separate ingredients. Aggregates shall conform to ASTM C33 or C330 required design specifications. The grading requirements (only) of ASTM C33 or C330 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. Specific gravity, absorption, and petrographic analysis performed within the past five years shall be obtained from the supplier prior to the time of

**1. Cement.**

Mill test reports should be reviewed for changes from previous reports. Lower concrete strength should be expected from: lower cube strength; lower C<sub>3</sub>S; lower fineness; higher percent retained on No. 325 sieve (45 mm); 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 Fe<sub>2</sub>O<sub>3</sub> content (a 2% variation in Fe<sub>2</sub>O<sub>3</sub> being significant).

An additional report is available from cement producers which allows the concrete producer to evaluate cement strength uniformity (ASTM C917). The data will show 7- and 28-day cube strengths with a five 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.

If the tricalcium silicate (C<sub>3</sub>S) content varies by more than 4% from the mean values used in mix design confirmation tests, the ignition loss varies by more than 0.5%, or the fineness by more than 375 cm<sup>2</sup>/g, Blaine (ASTM C204), then problems in maintaining a uniform high strength may result. Sulfate (SO<sub>3</sub>) variations should be limited to ± 0.20%.

Until project acceptance, it is good practice to keep a 10- to 15-lb sample of each cement shipment (composite from 2 or 3 subsamples) in an airtight and moisture-proof container with a minimum air space over the sample to check color and strength development, if necessary.

**2. Aggregates.**

Sampling of stockpiles or conveyor belts for aggregates should be in accordance with ASTM D75. Once a sample has been taken, the sample should be mixed and then quartered in accordance with ASTM C702. Once the sample has been reduced to a test size, testing should follow ASTM C136. 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.

**Standard****Commentary**

first usage, when a new lift or horizon in a quarry is utilized, or there appears to be a change in quality of the aggregate.

Specific gravity and absorption of normal weight 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.

Petrographic analysis should be made in accordance with ASTM C295 to ensure that selected aggregates are durable, inert, and free from iron sulfide (pyrite) and 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.

The specific gravity of lightweight aggregate shall be determined in accordance with procedures described in ACI 211.2, Appendix A - Pycnometer Method. The oven-dry loose unit weight (ASTM C29) 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.

For some relatively smooth-surface, lightweight coarse aggregates, regular specific gravity and absorption procedures by ASTM C127 can be used; however, 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 mix proportions may be required as properties change. Suppliers should forward gradation analyses and specific weight tests of the material with all initial shipments. The specific weight test or weight of 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 mix design.

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 aggregates and determine the

When possible, aggregates should be evaluated from 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.

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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 CSA A23.2-14A. Aggregates which exhibit ASTM C1260 mean mortar bar expansion at 14 days greater than 0.10% shall be considered potentially reactive. Aggregates further evaluated by CSA A23.2-14A 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 evidence of reactivity in the field shall be considered nonreactive. 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.

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.

Staining due to iron sulfide generally becomes noticeable after a period of time in service due to moisture and oxidation from exposure to the atmosphere.

**3. Water.**

Water shall be potable, or chemically analyzed when a private well or nonpotable water is used in the concrete mix. 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.

Mortar cubes made in accordance with ASTM C109 using nonpotable or questionable mixing water shall have 7-day strengths equal to at least 90% of the strengths of companion specimens made with potable or distilled water. Time of set (ASTM C191) for mortar made with questionable water may vary from one hour earlier to 1-1/2 hours later than the control sample made with potable or distilled water. Water resulting in greater variations shall not be used.

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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 reinforcement, and prestressing materials in stock or in use shall be required and indicate that the material meets the requirements of applicable ASTM specifications and ACI 318.

Certificates shall be obtained for each size and shipment and for each grade of steel. Mill certificates for all reinforcing materials shall be kept on file at the plant for at least five years after use. Certificates shall be obtained and kept on file for each 10 reels or coils of prestressing strand or wire in each size, and for each heat, or at least for each shipment if less than 10 reels or coils. Incoming steel, wire, and strand shall be examined for damage, excessive scaling, or pitting. The capability of the strand to properly develop bond shall either be substantiated by certification from the strand supplier or by testing. The stress-strain curve of the prestressing steel shall be on record. Stress-strain curves 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

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, the welding criteria (if welding is to be utilized for reinforcing steel) 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.

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 material. Rusting is generally acceptable if the rust is light and pitting has not begun. If rust can be removed by finger pressure or by the use of a nonmetallic pad, it generally is not a 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, bars, or wire provide an area where stresses are concentrated, and breakage can occur. Material which is received with kinks or nicks should not be accepted.

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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 have not 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 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, Types A, B, D, F, and G, or ASTM C1017. The supplier shall certify these admixtures do not contain calcium chloride. Fly ash or other pozzolans used as admixtures 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 chemical admixtures used at maximum dosages less than 5 fl oz per 100 lb (325 ml per 100 kg). Both the chloride 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

**5. Admixtures.**

The proprietary name and the net quantity in pounds (kilograms) or gallons (liters) should be plainly indicated on the package or container in which the 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, C233, and C1017.

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 an application basis, the final use of the precast element, and whether the element 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.

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**Commentary**

(milliliters per 100 kg).

**6. 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 of 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 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.

**7. Vendor-Supplied Assemblies.**

When assemblies are produced outside the precast concrete plant, the vendor producing the assemblies shall test assemblies in accordance with the testing procedures in Articles 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 stud welding 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 a 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.

**6. Hardware and Inserts.**

If suppliers' load tables indicate adequate capacity at a concrete strength lower than the design concrete strength, the insert capacity is considered to be satisfactory.

**7. Vendor-Supplied Assemblies.**

The heads of anchor studs are sometimes subject to cracks or "bursts" during manufacturing. This is essentially a crack starting at the edge of the head and progressing toward the center. As long as the cracks do not extend more than half the distance from the edge to the shank, as determined by a visual inspection, the crack is 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.

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Weld size and location shall be checked for welded assemblies at a rate of one per 50 assemblies. If discrepancies are found, then all assemblies shall be checked.

Weldability characteristics of reinforcing bars are usually different than deformed bar anchor studs, and strengths may not be the same.

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 products supplied. The tests shall correlate to the material supplied. One unit for each 50 assemblies received shall be selected and the stud weld(s) visually inspected, with one stud bend tested in accordance with the procedures detailed in Article 6.2.3(9).

**8. Curing Compounds, Form Release Agents, Surface Retarders, and Weatherproofing Sealers.**

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.

**9. Concrete Mixtures.**

Concrete mix proportions shall be established under carefully controlled laboratory conditions. For concrete mixes, representative cylinders shall be cast and cured under plant production conditions to demonstrate the strength and weight of the concrete produced. All concrete mixes 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 mixes. If at any time these variables are changed, the mix shall be reevaluated. This reevaluation may include one or more of the following concrete properties: (1) air content, (2) durability, and (3) strength (selected tests at appropriate ages).

**9. Concrete Mixtures.**

Casting of a mix in a critical part of an actual form is often advisable for checking a mix under production conditions.

Records of all concrete mixes used in a plant and their respective test results shall be on file. Acceptance tests for concrete mixes shall include:

- a. Compressive Strength.  
Standard test specimens (6 x 12-in. [150 x

- a. Compressive Strength.  
Typically, the 28-day design strength

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300-mm] cylinders, or 4 x 8-in. [100 x 200-mm] cylinders, or 4-in. [100-mm] cubes) shall be made and cured in accordance with ASTM C192 and tested in accordance with ASTM C39. Test specimens using 4-in. (100-mm) cylinders or cubes are permitted provided proper and proven correlation data with the standard 6 x 12-in. (150 x 300-mm) test cylinder are available. Compression tests shall be performed for determination of design, release of tension, and stripping strength.

established for concrete mixes should be not less than 5000 psi (34.5 MPa).

- b. Slump.  
Slump tests shall be made in accordance with ASTM C143.
- c. Unit Weight.  
Unit weight shall be tested in accordance with ASTM C138 or C567.
- d. Air Content.  
Air content shall be measured in accordance with ASTM C173 or C231 as applicable.

- b. Slump.  
The standard slump test may be inadequate as a measure of the workability of concretes with high proportions of coarse aggregate.
- d. 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) 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 concretes made with lightweight aggregates, air-cooled blast-furnace slag, or aggregates of high porosity. It also may not give accurate results on very harsh or low-slump mixtures.

**6.2.3 Production Testing**

Production testing shall be directed towards maintaining production and product uniformity by routine testing of materials and concrete to ensure consistency with the supplier's reported data or established requirements.

**C.6.2.3 Production Testing**

Quality control charts displaying production test results should be used to uncover unanticipated variations in materials, batching, mixing, curing, and testing of concrete. The primary objective of quality control charts is to test whether a process is in control. 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 information on the use of control charts, refer

**Standard**

**Commentary**

**1. Aggregates.**

A sieve analysis (ASTM C136) and unit weight test (ASTM C29) shall be conducted in the plant with test samples taken at any point between stockpile and batching hopper for aggregate being used. A minimum of one test per aggregate size or type shall be performed per the volumes shown below. Where the volume of aggregate used in a one-week period is less than that shown below, the minimum rate of testing shall be one test per week per aggregate size or type.

- a. fine aggregates – 500 tons
- b. coarse aggregates – 1,000 tons

Moisture tests are not required for bagged aggregates stored indoors. Surface moisture in

to ACI Manual of Concrete Inspection, SP-2, and Gebler, Steven H., "Interpretation of Quality Control Charts for Concrete Production," ACI Materials Journal, July/Aug., 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 possible is that from a conveyor belt. For fine aggregate, take scoops from the belt until a 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 no 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 ensure control of the concrete mix. 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 mix 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 mix 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 mixes where the amount of fine

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bulk aggregates shall be evaluated and compensated for in all concrete proportioning. Moisture content shall be determined by drying (ASTM C566), with a meter that measures moisture by the pressure of chemically generated gas, with an electric probe that indicates moisture by measuring the resistance between electrodes, by microwave energy absorption, or by other devices calibrated against the ASTM C566 test method.

Either the moisture meter or electric probe is satisfactory for continuous moisture determination provided the meters are calibrated against the drying method (ASTM C566).

If moisture meters are not used, the free moisture shall be determined at least daily, or at any time a change in moisture content becomes obvious.

**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 Fresh Concrete  
 ASTM C31 — Making and Curing Concrete Test Specimens in the Field

The size of specimens made and cured in accordance with ASTM C31 are amended to permit use of either 6 x 12-in. (150 x 300-mm) or 4 x 8-in. (100 x 200-mm) test cylinders.

Maximum size of aggregate in 4 x 8-in. (100 x 200-mm) cylinders should not exceed 1 in. (25 mm). If larger sized aggregate is used in the concrete, the compressive strength shall be measured using standard 6 x 12-in. (150 x 300-mm) cylinders.

Four compression specimens shall be made daily for each individual concrete mix, or for each 75 cu. yds. (57 m<sup>3</sup>) of a given concrete mix design where the daily consumption exceeds this volume. In the case of individual forms for small units having the same mix but non-continuous batching or dissimilar curing, a minimum of two test cylinders shall be made for each 20 cu. yds. (15 m<sup>3</sup>) or fraction thereof to verify handling strength or strength at stress

aggregates batched by weight vary enough to seriously affect the concrete mix. 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 under-yielding of concrete mixes. 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 mixes adjusted at any time. Readings from 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.

**2. Concrete Strength.**

Testing of concrete strengths by using test 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.

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transfer.

The required average strength of the concrete shall be selected in accordance with ACI 318, Chapter 5, Concrete Quality, Mixing, and Placing,

Cylinder molds shall be kept clean and free from deformations and shall conform to the requirements of ASTM C470.

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 hour 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 form. 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  $73^{\circ} \pm 3^{\circ}\text{F}$  ( $23^{\circ} \pm 1^{\circ}\text{C}$ ) until the time of testing.

Unless specimen ends are cast or ground to within 0.002 in. (0.05 mm) of a plane surface, the specimens shall be capped prior to testing or unbonded caps (elastomeric pads) may be used in accordance with ASTM C1231. 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 hour 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.

The strength of a test specimen can be greatly affected by jostling, changes in temperature, and exposure to drying, particularly within the first 24 hours after casting. Thus, test specimens should be cast in locations where 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 to 20 minutes. Concrete in cylinders may be consolidated by rodding or by vibration as specified in ASTM C31. Any deviations from the requirements of ASTM C31 should be recorded in the test report. If vibrators are used, techniques should be developed to preclude segregation.

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Testing of specimens to determine compressive strength shall be performed in accordance with ASTM C39. The strength of concrete at any given age shall be determined as the average of two specimens, except only one specimen may be used to determine stripping or stress transfer strength as production progresses. If either specimen shows definite 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 of 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. No individual strength test (average of two cylinders) is more than 500 psi (3.4 MPa) below the specified strength.

Nondestructive tests (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 methods shall be acceptable provided the following conditions are met:

- a. A correlation curve is established for each combination of concrete mix 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.

Nondestructive testing is testing 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 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 mix design.
- c. If values that are consistently within the 95% confidence limit cannot be obtained during testing using the nondestructive test method, 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.

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- d. Correlation curves shall be established for each test instrument, even of the same type.

Where concrete strengths are to be evaluated by an impact hammer in accordance with ASTM C805, 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. Care shall be taken not to obtain readings on an isolated piece of coarse aggregate at the surface or on any surface imperfection or directly over reinforcing steel or 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 because test results were more than 500 psi below specified strength (ACI 318, Article 5.6.2.3.b), 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. If the unit represented by the cores will be dry under service conditions, cores shall be air dried (at room temperature 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.

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 exposed surface finish. Core holes should be adequately patched without damage to the appearance or structural integrity of the element.

When possible, cores should be drilled so that the test load 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 2 extra in. (50 mm) of length at the broken end should be allowed to permit sawing off ends to plane surfaces before capping. If any core shows evidence of damage prior to testing, it should be replaced.

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.

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**3. Slump.**

Slump tests for each concrete mix design shall be made in accordance with ASTM C143 at the start of operations each day, when making strength test specimens, when the consistency of the concrete appears to vary, and at least one per every three air content tests.

The following tolerances 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:

- a. Slump specified as "maximum" or "not to exceed," for all values +0 in.
- b. Slump specified as 3 in. (75 mm) or less, +0, -1-1/2 in. (+0, -38 mm)
- c. Slump specified as greater than 3 in. (75 mm), +0, -2-1/2 in. (+0, -63 mm)
- d. Slump specified as a single value:
  - Slump of 4 in. (100 mm) or less, ±1 in. (±25 mm)
  - Slump that is more than 4 in. (100 mm), ±1-1/2 in. (±38 mm)
- e. Slump specified as a range, the range is the tolerance.
- f. For superplasticized concrete ±2-1/2 in. (±63 mm)

**4. Air Content.**

If an air-entraining admixture is used, the air content shall be measured in accordance with ASTM C173 or C231 as applicable. Air content shall be tested periodically during the daily operation with a minimum of one daily check per mix design or when making strength test specimens.

Variations from the specified value of air content shall not exceed 1-1/2 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 ±1 in. (25 mm),

**3. 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 mix.

f. Flowable concrete achieved by the incorporation of high-range water reducers (HRWR) (superplasticizers) 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 an HRWR is used to achieve flowable concrete.

**4. Air Content.**

The volumetric method of measuring air content (ASTM C173) may be used on any type of aggregate, whether it is dense, cellular, or lightweight. The pressure method (ASTM C231) gives excellent results when used with concrete made with relatively dense, natural aggregates for which an aggregate corrections factor can be determined 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 the air in the void system. The volumetric method, ASTM C173, is not subject to this limitation and should produce accurate results on even the driest concrete. Although these tests

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temperature of the concrete varies more than  $\pm 10^{\circ}$  F ( $6^{\circ}$  C), a change in aggregate grading occurs, or there is a loss in concrete yield.

measure only air volume and not air-void characteristics, which can only be determined microscopically (ASTM C457), it has been shown by laboratory tests that these methods are generally indicative of the adequacy of the air-void system.

**5. Unit Weight.**

Unit weight tests of concrete in accordance with ASTM C138 shall be carried out at least once per week for each mix design regularly used, except for lightweight concrete, which shall be tested daily in accordance with ASTM C567 to confirm batching consistency. When the nominal fresh unit weight varies from the established value by more than  $\pm 2$  lbs per cu ft ( $\pm 32$  kg/m<sup>3</sup>) for normal weight concrete or  $\pm 2\%$  for structural lightweight concrete, batch adjustments shall be made.

**5. Unit Weight.**

The 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 unit weight measurements (ASTM C138 or C567) indicate a variation of the calculated fresh unit weight from the laboratory mix design of more than 2 lb per cu ft (32 kg/m<sup>3</sup>) for normal weight 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 mix adjustments need to be made. After adjustments are made, the unit weight should again be measured.

The unit weight 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.**

The temperature of freshly mixed concrete shall be measured in accordance with ASTM C1064 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.

**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 mixes of the same slump without admixtures, unless more cement is used in the warmer concrete, the concrete will have a higher water-cementitious material ratio. Warm concrete gains strength faster than cool concrete, but the strength at later ages may be lower than that of cool concrete. Knowledge of the temperature of fresh concrete permits the batch plant operator to adjust mixes. 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 and ensure

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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 (oven dry) are used, and 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 bases:

- 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.

The qualification of the responsible personnel 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

Visual inspection guidelines are given in AWS B1.11 while radiographic and ultrasonic testing procedures and limits are given in AWS D1.1 and D1.4. If required by specifications, radiographic

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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.

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.

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.

Prior to welding, inspection shall include the following:

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.

- a. Review of welding drawings and welding procedure specifications.
- b. Assuring that welding materials and consumables are in accordance with specifications.
- c. Checking and identifying as-received materials against specifications.
- d. Checking storage of filler material.
- 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 and chipping hammer to remove slag).
- g. Conformance with the applicable procedure, i.e., voltage, amperage, heat input, and/or speed.

The following items shall be inspected on at least 10% of all assemblies after welding to determine the quality of the welds:

- a. 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

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- shows similar acceptable and unacceptable profiles for groove type welds.
- b. The weld metal and heat-affected zone of the base metal shall be free of cracks.
  - c. There shall be thorough fusion between weld metal, base metal, and successive passes in the weld.
  - d. 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.
  - e. Welds shall be free from overlap. Overlap is the protrusion of weld metal beyond the weld toe or root weld.
  - f. 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.
  - g. 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) length of weld. For steel shapes or plates, refer to AWS D1.1 for the requirements of the specific structure type.
  - h. Incomplete joint penetration.
  - i. Slag inclusions.
  - j. 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.

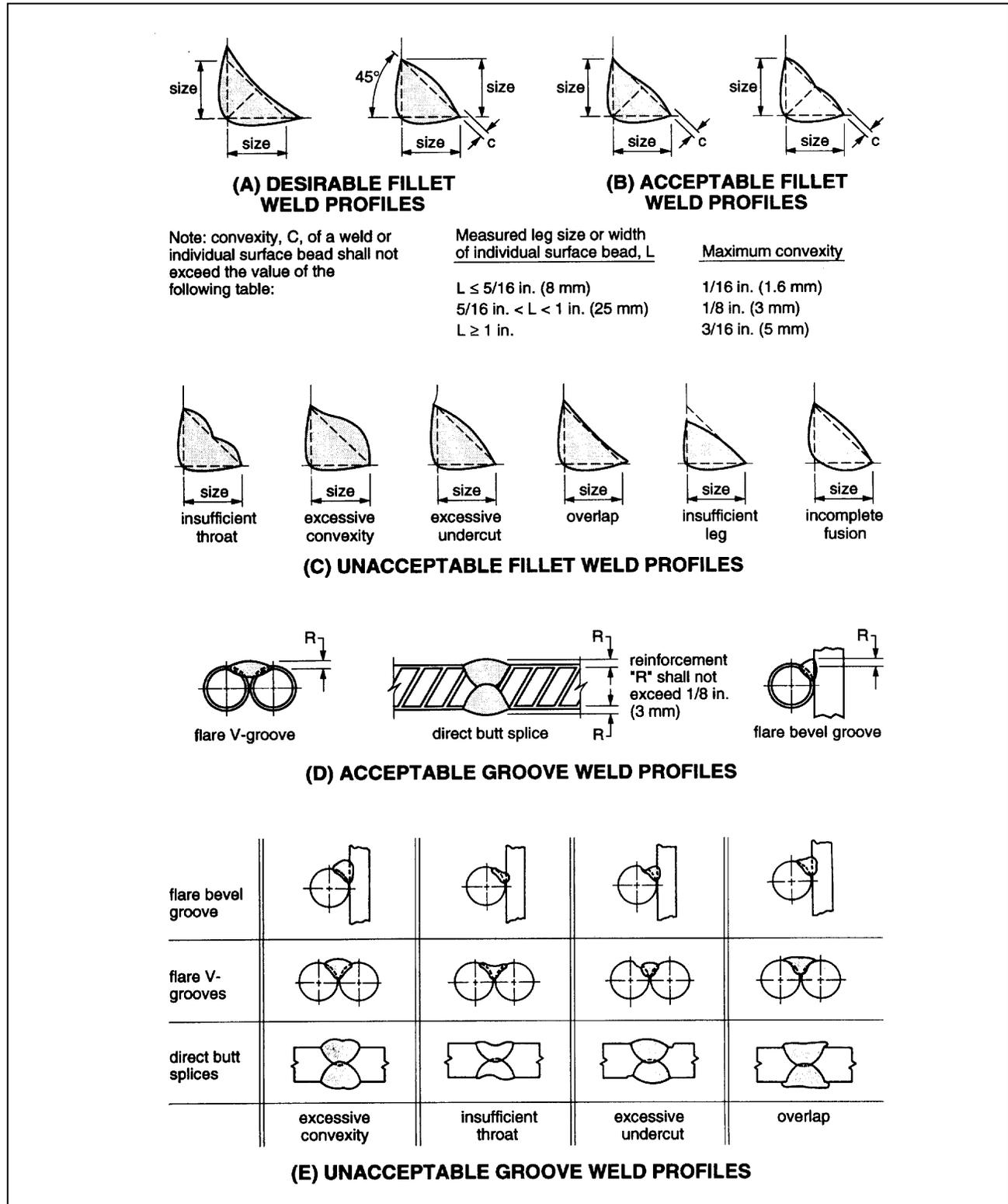
Weldments shall be checked after fabrication for brittleness by striking at least one out of every 50 pieces with a 3-lb (1.3-kg) hammer. Brittle weldments will break under a hammer blow. When such brittle weldments are found, all assemblies made using similar procedures shall be considered suspect and checked for acceptance.

Deficient welds shall be corrected by rewelding or removal in accordance with specified procedures.

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Figure 6.2.3(a). Weld Profiles.



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**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's production and for changes in the setup such as: stud gun, stud welding equipment, stud diameter, gun lift and plunge, total welding lead length, or changes greater than 5% in current (amperage) and dwell time.

**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.

At temperatures below 50° F (10° C), some stud and base materials may lack adequate toughness to pass a hammer test.

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.

**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 ±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 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:

**Table 6.2.3(a). Length Reductions.**

<b>Stud Diameter in. (mm)</b>	<b>Length Reduction in. (mm)</b>
3/16 through 1/2 (5) through (12)	1/8 (3)
5/8 through 7/8 (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

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studs shall be bent to an angle of approximately 30 degrees 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 to a proof load of approximately 90% of the specified yield strength rather than bend tested.

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 studs shall be welded and satisfactorily bend tested to 90 degrees 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 if required by the specification.

Threaded studs should be proof-loaded to demonstrate acceptable torque values as shown in Table C6.2.3(a).

**Table C6.2.3(a). Proof Loads – Threaded Studs of A-108 Carbon Steel.**

<b>Torque Proof Loads – Threaded Studs A-108 Carbon Steel</b>					
<b>Stud Size (diameter)</b>		<b>Proof Load (90% of Min. Yield)</b>		<b>Minimum Stud Yield</b>	
<b>in.</b>	<b>UNC</b>	<b>ft.-lbs.</b>	<b>lbs.</b>	<b>ft.-lbs.</b>	<b>lbs.</b>
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
<b>Torque Proof Loads A-276/A-493 Stainless Steel</b>					
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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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 straightening performed with a continuous, slowly applied load. The bent stud may also be used without straightening 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 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 one-hour intervals. The number of studs welded by a single operator in one hour 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-degree 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-degree flash, shall then be bent approximately 15 degrees 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-degree weld flash shall be torque tested to the required proof load to produce 90% of the specified stud yield strength.

**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 the 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.

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At the option of the welding operator, studs with a satisfactory after-weld length, but lacking a full 360-degree 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.

**Table 6.2.3(b). Minimum fillet weld size for studs.**

Stud Diameter In. (mm)	Minimum Size Fillet*, in. (mm)
1/4 through 7/16 (6) through(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 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) diameter or under or for out-of-position welds.

Studs with unsatisfactory weld burn off and lack of a full circumferential flash shall be repaired with a fillet weld, bent 15 degrees, and straightened or torque-tested.

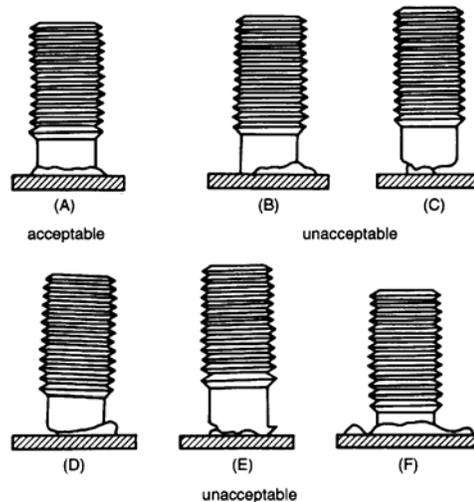
Studs that fail the inspection test by breaking off or tearing in the weld zone shall be removed. The weld spot shall be ground smooth and the stud replaced.

**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 the 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

**Figure C6.2.3(a). Satisfactory and unsatisfactory arc stud welds.**



**Standard**

**Commentary**

15 degrees and straightening without failure.

After a production welding period of one hour, 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 fail 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.

**6.2.4 Special Testing**

**1. Heat of Hydration.**

For massive concrete castings when partly or fully insulated forms 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 180°F (82°C), steps shall be taken in all future castings to cool the concrete.

**C6.2.4 Special Testing**

**1. Heat of Hydration.**

In precast concrete members, most of 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,

**Standard**

**Commentary**

**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, Method B) shall be followed. Under this test method, the minimum allowable durability factor as defined by ASTM C666 shall be 70.

**6.3 Records**

**6.3.1 Recordkeeping**

In order to establish evidence of proper manufacture and conformance with plant standards and project specifications, a system of recordkeeping shall be used that will provide full information regarding testing of materials, mix designs, production tests, and any other

because of heat of hydration, and then cools to the temperature of its surroundings. 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 the 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 were restrained by the interior concrete. Accordingly, the maximum permissible temperature gradient between any points in the element for a nominally reinforced structure generally should not be allowed to exceed 100°F (38°C).

**2. Freeze-Thaw Tests.**

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 mixes 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. Possible exceptions to this are applications that require very high concrete strengths.

Equivalent evaluations can be obtained more rapidly by conducting “air void studies” (amount and character of entrained air in cores taken from the production unit) in accordance with ASTM C457.

**C6.3 Records**

**C6.3.1 Recordkeeping**

Records provide the vehicle for transmitting and evaluating and should facilitate correction of deficient procedures or products through communication of problems.

**Standard****Commentary**

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 of the unit with the date produced and a unique identification number that can be referenced to production, erection drawings, and testing records.

Unless otherwise noted herein, recordkeeping 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 5 years after final acceptance of the structure, or for the period of product warranty provided by the manufacturer, whichever is longer.

**6.3.2 Suppliers' Test Reports**

Certified test reports for materials not tested in-house shall be required of suppliers. Refer to Article 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 mixes, and other testing required by the project specifications. These reports shall state compliance with applicable specifications.

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
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

Units should be marked in an area that is not exposed to view when in place on the structure, but accessible for review and inspection while in storage at the precast concrete plant.

Member markings, related to form number when several identical forms are needed, make it possible to relate quality control data to specific units. Such markings also facilitate documentation of member production, inspection, and repair.

**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 to ensure compliance with the specifications of this manual. All vendors should be required to submit proof of compliance for both materials and workmanship.

**Standard**

**Commentary**

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 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 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 the jacking force shall be recorded.
10. For multiple-strand pretensioning, the actual elongation of the strand group measured by movement of the jacking header.
11. For post-tensioning:
  - a. The jacking force and actual net elongation of each tendon with allowance made for elastic shortening of the member.

**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.

**Standard**

**Commentary**

- b. Data on and date of grouting.
- 12. Any unanticipated problems encountered during tensioning such as wire breakage, excessive seating, prestressing, 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. Mix proportions by weight
- 4. Mixing water corrections and/or aggregate corrections due to surface moisture
- 5. Yardage, design and actual yield or unit weight
- 6. Identification of production area, form, 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
- 11. Air content
- 12. Unit weight (fresh)
- 13. Inspection of batching, mixing, conveying, placement, consolidation, and finishing of concrete
- 14. Method and duration of curing, e.g., temperature charts for accelerated curing
- 15. Strength at stress release or stripping
- 16. 28-day strength
- 17. Absorption for concrete exposed to weathering (see MNL-117-96, Art. 6.2.2(10) (b))
- 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 machine, impact hammer, nondestructive testing devices, and other necessary equipment shall be supplied by the testing agency or others involved in calibration, and the equipment operator shall have ready access to the records.

**6.3.4 Concrete Records**

In evaluating mix 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.

**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.

**Standard**

**Commentary**

**6.4 Laboratory Facilities**

**C6.4 Laboratory Facilities**

**6.4.1 General**

**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 mixes 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 condition and calibrated as needed, but not less than annually. Calibration records shall be kept on file.

**6.4.2 Quality Control Testing Equipment**

**C6.4.2 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.

The laboratory should have the facilities necessary for the development and assessment of concrete mixes 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.

**6.4.3 Test Equipment Operating Instructions**

**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 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.

**Standard****Commentary**

Testing machines shall be calibrated so that the maximum error is not more than  $\pm 1\%$  of full scale reading or  $\pm 2\%$  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.

## **DIVISION 6 – QUALITY CONTROL**

### **PROVISIONS FOR SPECIAL FINISHES**

The following Articles, designated with an “A” prefix, apply to structural products with an architectural finish requirement. Conformance with the requirements of the Articles is required as part of certification in the Product Categories “Bridge Architectural” (BA), or “Commercial Architectural” (CA) within the Bridge Products and Commercial (Structural) Products Groups. For a description of these Groups, see Appendix F, *Certification Programs – Product Groups and Categories*.

The criteria established in this manual govern except as specifically modified by these provisions for the special class of products defined above.

The Article numbers are the same as the corresponding Articles in the main portion of the Standard. Where a special provision for architectural finishes does not have a matching Article in the main portion of the Standard, the provision is placed at the end of an Article or the Division with numbering continued sequentially.

#### **Standard**

#### **Commentary**

##### **A6.1 Inspection**

##### **AC6.1 Inspection**

###### **A6.1.2 Scope of Inspection**

###### **AC6.1.2 Scope of Inspection**

10. Inspection of finish to make sure that the product matches the standard established by the approved project mock-up or sample in 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 marked.
11. Check finished product to ensure that proper finishes are on all required areas.

Items 10 and 11 are to be added to the scope of inspection for structural products when producing to the standards for Category BA or CA.

# DIVISION 7 – PRODUCT TOLERANCES

## Standard

## Commentary

### 7.1 Requirements for Finished Product

Dimensional control of precast concrete elements shall be within the tolerances shown in Appendix B, *Product Dimension Tolerances*, or as required by the contract documents for a specific project.

### C7.1 Requirements for Finished Product

The product dimensional tolerances given in Appendix B are based on typical construction requirements and a reasonable expectation of the control that can be achieved with standard precast concrete production techniques.

Project specifications may require small, or allow for large, tolerance limits depending upon the construction details and provisions for interfacing with other materials. Structures should be designed to permit the maximum reasonable limits on dimensional variations. For a complete discussion of precast construction tolerances, including erection and interfacing tolerances, see PCI Report, “Tolerances for Precast and Prestressed Concrete” written by the PCI Committee on Tolerances.

Tolerances are specified permissible variations from exact requirements of the contract documents. A tolerance may be expressed as an additive or subtractive (+) variation from a specified dimension or relation, or as an absolute deviation from a specified relation.

Tolerances should be established for the following reasons:

1. **Structural** – To control the member dimensions and dimensional interface in order to ensure that variations do not change the loading configuration or capacity of a member as assumed by the designer. Examples include eccentric loading conditions, bearing areas, reinforcement locations, hardware, and hardware anchorage locations.
2. **Feasibility** – To ensure acceptable performance of joints and interfacing materials in the finished structure and to ensure that designs are attainable with available manufacturing and construction techniques.
3. **Visual Effects** – To ensure that the variations will be controllable and result in acceptable appearance.
4. **Economics** – To ensure a reliable and efficient rate of production and erection by having a known degree of accuracy in the dimensions of the precast concrete units.
5. **Legal** – To avoid encroaching on property lines and to establish a tolerance standard against which the work can be compared in the event of a dispute.
6. **Contractual** – To establish a known acceptability range and also to establish responsibility for developing,

**Standard**

**Commentary**

achieving, and maintaining mutually agreed upon tolerances.

It is very important to clearly define, at the onset of the project, the entity (architect, engineer of record, or precaster) responsible for establishing project tolerances.

The architect/engineer should be responsible for coordinating the tolerances for precast concrete work with the requirements of other trades whose work adjoins the precast concrete construction. In all cases, the tolerances should be reasonable, realistic, and within generally acceptable limits. It should be understood by those involved in the design and construction process that tolerances shown in *Appendix B* 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 these tolerances are exceeded, the unit may still be acceptable if it meets any of the following criteria:

1. Exceeding the tolerance does not affect the structural integrity of the unit.
2. The unit can be brought within tolerance by structurally satisfactory means.
3. The total erected assembly can be modified to meet all structural requirements.

Where a project involves particular features sensitive to the cumulative effect of generally accepted tolerances, the architect/engineer should anticipate and provide for this by setting a maximum cumulative tolerance or by providing sufficient clearances where accumulated tolerances can be absorbed.

Specified tolerances should allow for construction with industry standard means and methods. Specifications should be reasonable with respect to the level of precision that can be attained with standard manufacturing methods. For example, a requirement that states that “no bowing, warpage, or movement is permitted” is not practical or possible to achieve.

Required tolerances other than those given in this Manual, should be noted on the product drawings or in a special tolerance document.

Applicable product tolerances shall be clearly conveyed to production and quality control personnel.

**7.2 Measurement**

Accurate measuring devices and methods with a level of precision that is appropriate for the specified tolerance, shall be used for both setting and

**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

**Standard**

checking product dimensions. To ensure proper accuracy, products shall not be measured in a manner that creates the possibility of cumulative error such as measuring multiple increments for single dimensions.

**Commentary**

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 inch (3 mm).

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.

# ***DIVISION 7 – PRODUCT TOLERANCES***

## ***PROVISIONS FOR SPECIAL FINISHES***

The following Articles, designated with an “A” prefix, apply to structural products with an architectural finish requirement. Conformance with the requirements of the Articles is required as part of certification in the Product Categories “Bridge Architectural” (BA), or “Commercial Architectural” (CA) within the Bridge Products and Commercial (Structural) Products Groups. For a description of these Groups, see Appendix F, *Certification Programs – Product Groups and Categories*.

The criteria established in this manual govern except as specifically modified by these provisions for the special class of products defined above.

The Article numbers are the same as the corresponding Articles in the main portion of the Standard. Where a special provision for architectural finishes does not have a matching Article in the main portion of the Standard, the provision is placed at the end of an Article or the Division with numbering continued sequentially.

### **Standard**

#### **A7.1 Requirements for Finished Product**

Where products will be exposed to view, special manufacturing tolerances may be required to maintain the desired project aesthetics. These special tolerances shall be shown on the drawings.

### **Commentary**

#### **AC7.1 Requirements for Finished Product**

Typically, the tolerances for architecturally exposed products must be adjusted to accommodate reduced field installation tolerances. Special tolerances should be carefully selected to provide the desired finished product while being reasonable for the size and type of product involved.

Tolerances specified for Category BA or CA products should consider the opportunities and limitations of the type of manufacturing process used to fabricate the members.

# APPENDIX A

## Guide for Developing the Plant Quality System Manual

### INTRODUCTION

Documented quality system procedures should be the basis for the overall planning and administration of activities that impact 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, types of documentation, and the controls to be applied. All of this is particularly important for personnel who need the organizational freedom and authority to: 1) initiate action to prevent nonconformances of any kind, 2) identify and document any problems relating to product, process, and/or quality systems, 3) initiate, recommend, or provide solutions through designated channels, 4) verify the implementation of solutions, and 5) control further processing, delivery, or installation of nonconforming 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 would be to key the sections of the quality manual to the quality elements of this manual, MNL-116. 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 and coding system of sections, subsections, pages, figures, exhibits, diagrams, tables, etc., should be clear and logical and include revision status.

#### 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-116.

#### 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 is in conflict 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 satisfaction of their needs is going to be the point of reference in their relationship with the plant.
2. This section describes how the quality policy is made known to, and understood by, all employees. It should also describe how it is to be 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.

To ensure proper distribution of the quality manual, whether or not it contains confidential information, a statement should be included that

addresses 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 not practical or 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. While 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, which manage, perform, and verify work affecting quality, should be provided. Assignments 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 section.

**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 what level of training and experience is needed to perform specific verification functions and to evidence that the assigned personnel meet those requirements. All training, no matter how informal, should be documented and recorded.

b. Self-inspections 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 analysis of PCI Plant Certification audit results, rules for scheduling, conducting, and recording management reviews of the quality system should be established.

**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 responsibilities for establishing and maintaining the quality system documentation.

**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 also be included, if appropriate.

To ensure that each manual is kept up to date, a method is needed to ensure 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 provide assurance to the users that they have the authorized manual.

**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 nonconforming materials should be described.

Rules applicable to preparation, review, and approval of purchasing documents and use of approved vendors should be provided.

**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, products, and maintenance procedures for records.

**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, steps required to perform certain operations and inspections, warn against safety hazards, etc. Maintenance, calibration of equipment, and testing apparatus schedules should be established and recorded.

Establish a system with instructions that assigns the responsibility for:

1. Establishing and use of work order, work instructions, and change orders.
2. Production equipment checking and monitoring.
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.

**Inspection and Testing****A. Receiving Inspection and Testing**

The purpose of this section is to provide for a system with instructions, that assigns the responsibility for performing 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.
2. Visual inspection to detect any damage or other visible quality problems.
3. Taking measurements and testing, as required.
4. Recording and 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 requirements 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 nonconforming 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 nonconforming products should be described.

**D. Inspection and Test Records**

Describe the recording of each inspection, sign-off procedure, and the maintenance of records.

**Inspection and Test Records**

The purpose of this section is to provide 1) a system with instructions, 2) assignment of responsibilities for calibration at prescribed intervals, 3) identification including type, model, range, and accuracy, and 4) 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.

The system of checking and certifying jigs, templates, and patterns or molds used in manufacturing or inspection should be established.

**Corrective Action**

All activities relating to corrective actions should be covered by written procedures. The corrective action system should comprise investigation of causes, implementation of corrective actions, and verification of their effectiveness.

**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 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 to assign responsibilities for:

1. Ensuring products are stored in accordance with the drawings.
2. Use and maintenance of storage areas for both materials and finished products.
3. Periodical assessment of stored materials and product to check on damage, stains, or contamination.

**D. Loading/Delivery**

Describe the procedure for providing a system with instructions and assigning responsibilities for loading and protecting products during delivery, whether or not delivery is required by the contract.

**Quality Records**

Compliance with the following requirements should be documented in written procedures:

1. Identifiable and legible records.

2. Easily retrievable records for files in a suitable environment.
3. Retention of records for a specified period of time.

Recording procedures for employee participation in training and maintenance of the records should be discussed.

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.

### **Internal Quality Audits**

The purpose of this section is to provide for a system with instructions, and to assign responsibilities 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.

### **Training**

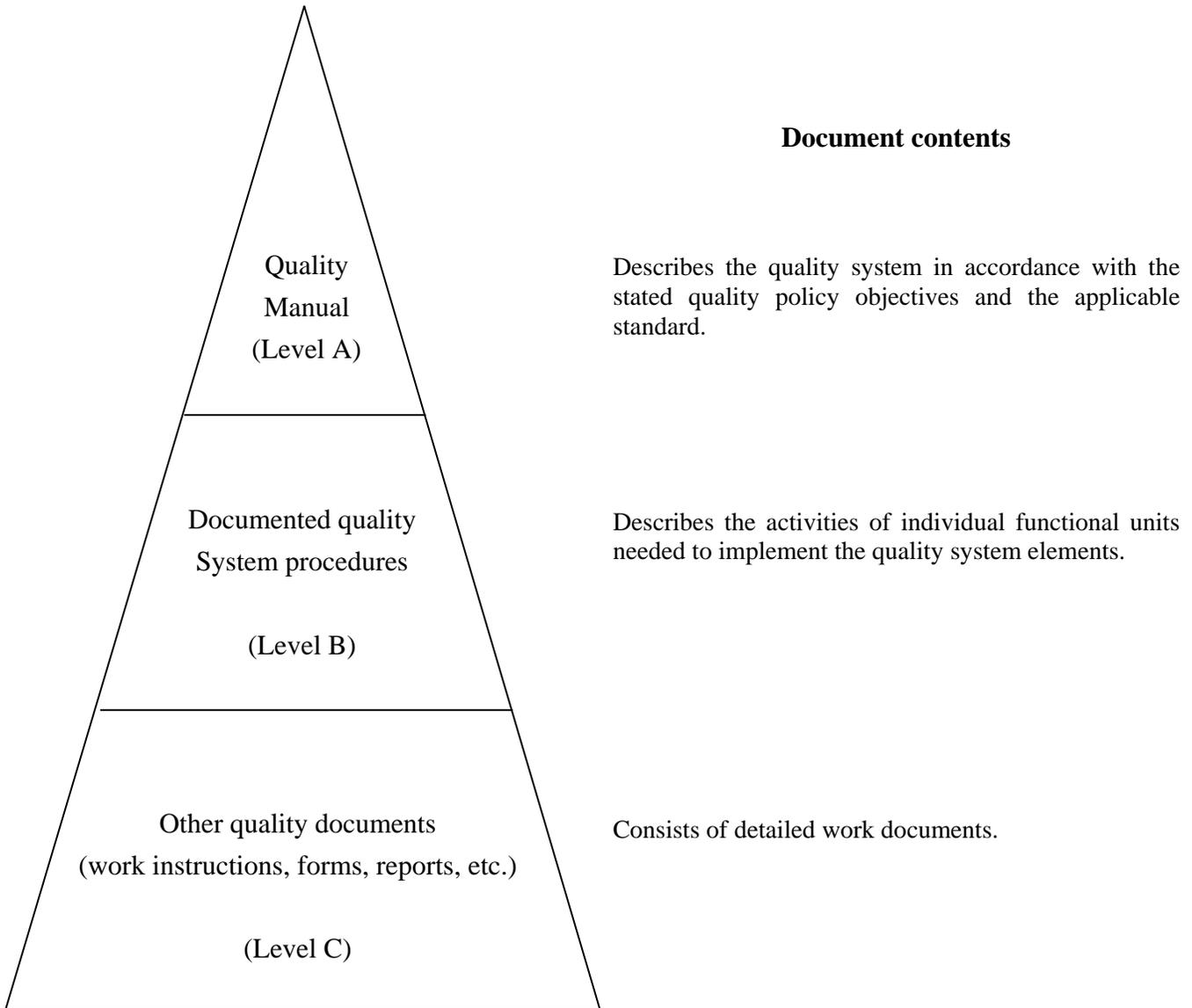
The purpose of this section is to provide for a system with instructions, and to assign responsibilities for determining training needs, providing the training, and keeping training records.

As a minimum, the training should comprise the following topics.

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.

<b>EXAMPLE OF POSSIBLE FORMATTING FOR A SECTION OF A QUALITY MANUAL</b>				
<b>Organization</b>		<b>Title-Subject</b>		<b>Number</b>
<b>Unit issuing</b>	<b>Approved by</b>	<b>Date</b>	<b>Revision</b>	<b>Page</b>
<b>Policy or Policy Reference</b>				
Giving governing requirement.				
<b>Purpose and Scope</b>				
List why, what for, area covered, and exclusions.				
<b>Responsibility</b>				
Give organizational unit responsible for implementing the document and achieving the purpose.				
<b>Actions and Methods to Achieve System Element Requirement</b>				
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>				
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>				
Identify which records are generated as a result of using the document, where these are retained, and for how long.				
<p>Notes:</p> <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.

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# **APPENDIX B**

## ***Product Dimension Tolerances***

Product tolerances are necessary in any manufacturing process. They are normally determined by function and appearance requirements, and by economic and practical production considerations. Tolerances for manufacturing precast products are standardized throughout the industry and should not be reduced, and therefore made more costly, unless absolutely necessary.

The tolerances listed herein are the minimum acceptable criteria in the absence of other specifications. Projects under the control of special authorities, such as state departments of transportation, will often have a full set of tolerances specified. In these situations, the tolerances specified by the controlling authority may govern.

For products not specifically listed, select the appropriate tolerances from the listed type (or types) that most closely matches the function of the product.

A dimensional layout and measurement plan is needed to control the production of precast elements so that the measurement process does not result in unintended accumulation of tolerances. 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 Appendix show the location of features to which the 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 engineer and shown on the production drawings.

### **Definitions and Notes on Tolerances**

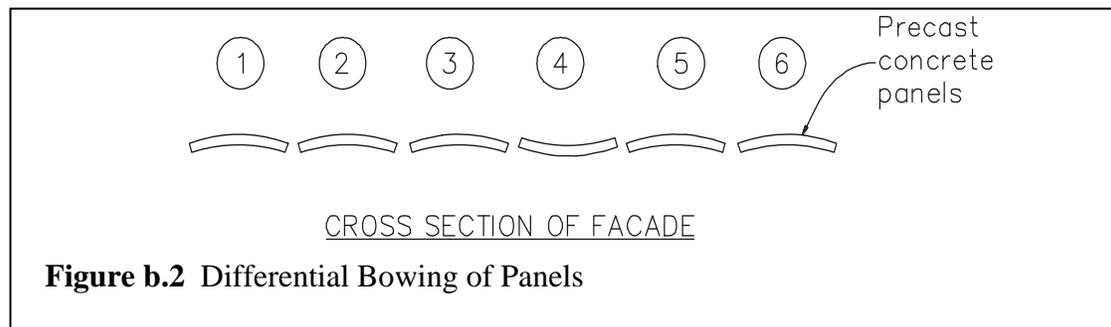
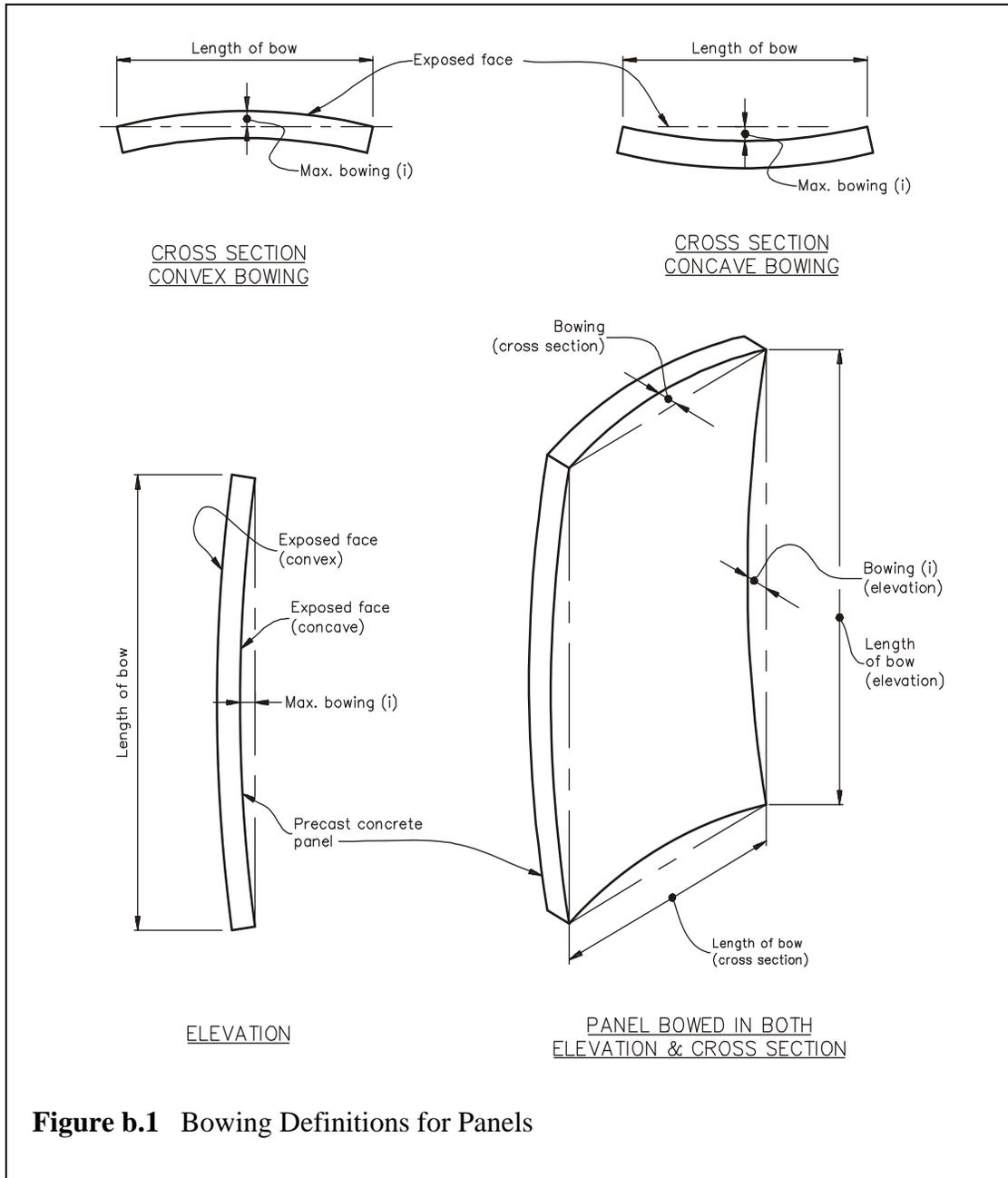
**Bowing and Warping** - Bowing is an overall out-of-plane curvature of a surface whose edges remain parallel (See Figure b.1).

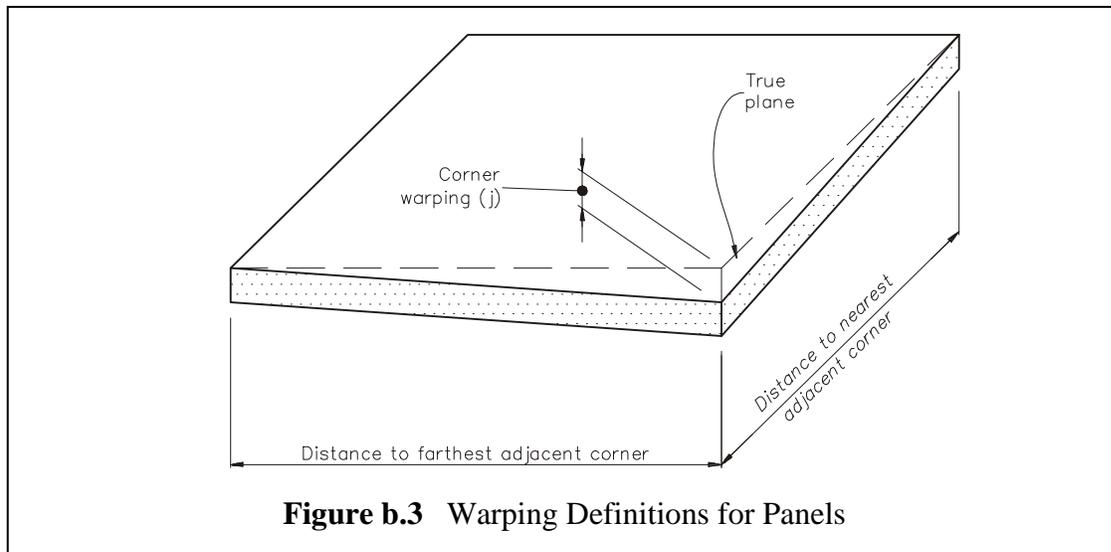
Differential bowing is a consideration for panels that are viewed together on the completed structure. If we use the convention that convex bowing is positive (+) and concave bowing is negative (-), then the magnitude of differential bowing can be determined by subtracting the bow in adjacent panels. For example, refer to Figure b.2. If the maximum bow in Panel 3 is + 1/4 inch [+ 6 mm] and the maximum bow in Panel 4 is - 1/4 inch [- 6 mm] then the differential bowing between the two adjacent panels is 1/2 inch [13 mm].

Warping is the twisting of a member, resulting in an overall out-of-plane curvature of surfaces, characterized by non-parallel edges (See Figure b.3).

Bowing and warping tolerances are often important aspects of panel visual features. They have an important influence on the visual effects relating to edge match-up during erection, and on the visual appearance of the erected panels, both individually and when viewed together. These tolerances also influence the ease of erection and functional performance of panel connections and panel interface elements.

Differential temperature effects and differential moisture absorption between the inside and 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 deflection as a plate member must be consistent with the specified tolerances. Panels that are relatively thin in cross section when compared to their overall plan dimensions are more likely to bow or warp as a result of member design, manufacturing and environmental conditions.





**Figure b.3** Warping Definitions for Panels

**Camber** - The deflection that occurs in prestressed concrete members due to the net bending resulting from the eccentricity of the prestress force. For members with span-to-depth ratio at or exceeding 25, the camber tolerance given herein may not apply. If the application requires control of camber to the listed tolerance in beams with high span-to-depth ratio, special production measures may be required. The precaster should be consulted regarding this requirement.

Prediction of camber in a prestressed member is based on empirical formulas. The accuracy of these estimated values decreases with time. Measurement of camber for comparison to predicted design values should be completed within 72 hours of transfer of prestressing force.

Temperature variation across a member section can have a significant impact on the measured camber. Camber should be evaluated under conditions that minimize the effect of temperature variation due to solar radiation, such as early in the morning.

When the finished floor or deck surface is created by the precast elements as erected (pretopped), the overall depth of the member becomes a primary control feature and the deck surface becomes a primary control surface for both fabrication and erection. In order to achieve the desired tolerances on the overall floor or deck it may be necessary to use special production measures to control camber and differential camber among the adjacent elements.

**Clearance** - Interface space (distance) between two elements. Clearance is normally specified to allow for the effects of product and erection tolerances and for anticipated movement (e.g., deflection, thermal movement).

**Cover** - The least distance between the surface of the reinforcement and the surface of the concrete element.

**Flatness** - The degree to which a surface approximates a plane.

**Harped (Deflected) Strand** - The path of a prestressing strand in a member may be altered from the horizontal to increase load carrying capacity or to control member stresses, or both. This practice is referred to as harping, deflecting, or depressing the strand.

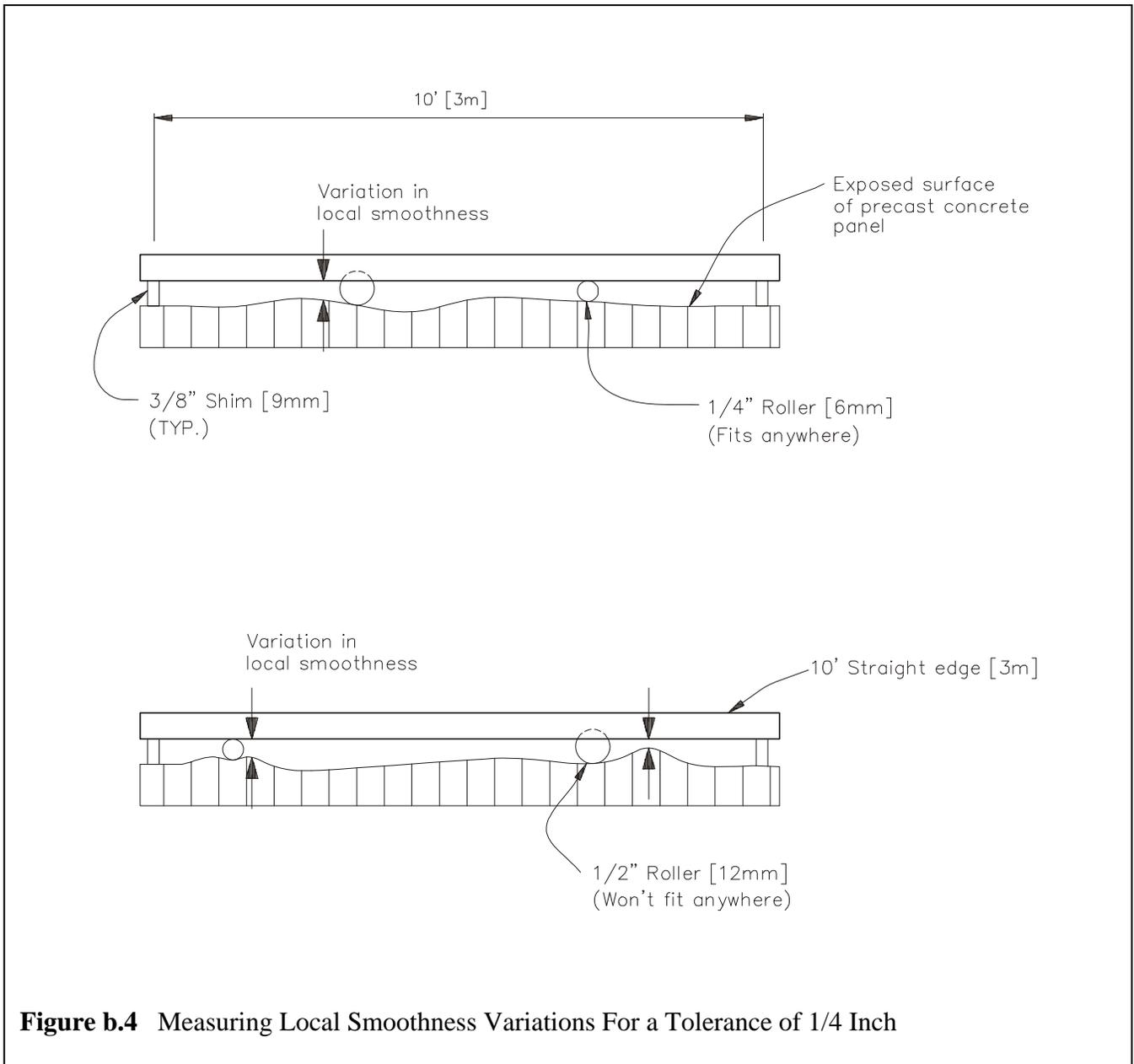
The economical location of strand harping points depends on individual form set-up characteristics. A large tolerance for this item generally has little design or structural consequence.

**Smoothness** - The degree to which a surface is locally flat (See Figure b.4).

The local smoothness criterion does not apply to visually concealed surfaces, or to surfaces intentionally roughened to receive a field-placed concrete topping. Smoothness is primarily a function of the form surface used to manufacture the

product. Requiring a smoothness tolerance on visually non-critical surfaces will unnecessarily increase project costs due to increased forming and surface finishing costs.

Local smoothness is usually expressed in inches deviation from a 10 ft. [mm/3m] straight edge. The tolerance should be checked with a 10 ft. [3 m] straightedge, or the equivalent, as shown in Figure b.4 unless other methods are specified or agreed to. Figure b.4 shows how to determine if a surface meets a tolerance of 1/4 inch [6 mm] as measured beneath a 10 ft. [3 m] straightedge. A 1/4 inch [6 mm] diameter roller should fit anywhere between the straight edge and the member surface being measured when the straightedge is supported at its ends on 3/8 inch [10 mm] shims as shown. A 1/2 inch [13 mm] diameter roller should not fit between the surface and the straightedge.



**Figure b.4** Measuring Local Smoothness Variations For a Tolerance of 1/4 Inch

**Sweep** - A variation in horizontal alignment from a straight line parallel to centerline of member (horizontal bowing).

**Tolerance** - Permissible variation from specified requirements.

**PRODUCT TOLERANCE LISTINGS - TABLE OF CONTENTS**

- B-1 Solid or Insulated Flat Wall Panel
- B-2 Ribbed Wall Panel
- B-3 Hollow-Core Wall Panel
- B-4 Double Tee (Untopped and Pretopped)
- B-5 Single Tee (Untopped and Pretopped)
- B-6 Solid Flat Slab
- B-7 Hollow-Core Slab
- B-8 Column
- B-9 Building Beam or Spandrel
- B-10 I-Beam (Girder) or Bulb-Tee Girder
- B-11 Box Beam
- B-12 Piling (Solid or Hollow)
- B-13 Sheet Piling
- B-14 Multi-Stemmed Bridge Unit
- B-15 Bridge Deck Unit
- B-16 Segmental Box Girder
- B-17 Pier Deck Panel
- B-18 Railroad Tie
- B-19 Stadium Riser
- B-20 Pole
- B-21 Tee Joist or Keystone Joist
- B-22 Stair Unit
- B-23 Modular Unit
- B-24 Storage Tank Panel

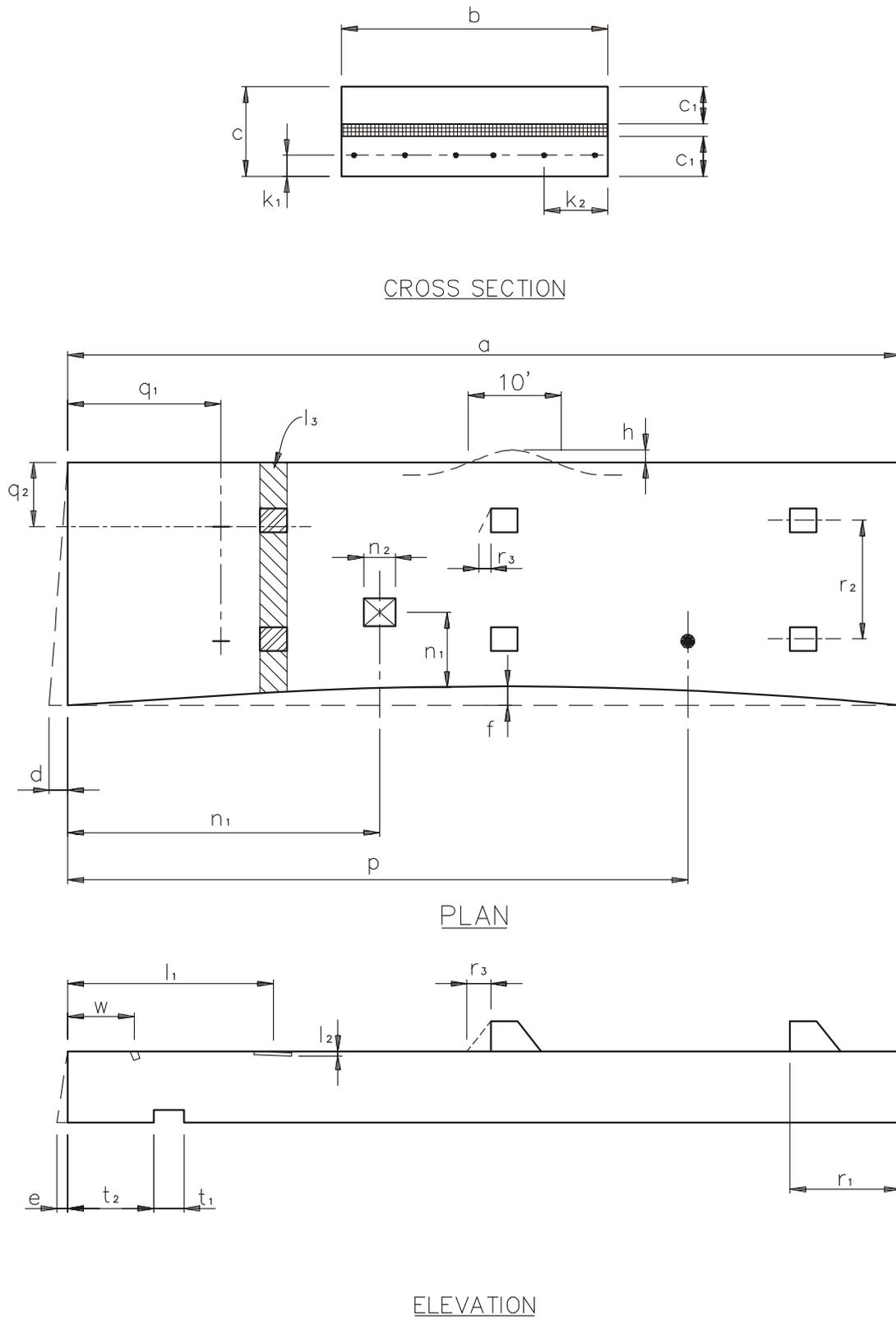


Figure B-1 Solid or Insulated Flat Wall Panel

## APPENDIX B

## Product Dimensional Tolerances

### B-1 Solid or Insulated Flat Wall Panel

a	= Length	.....	$\pm 1/2$ in. [ $\pm 13$ mm]
b	= Width (overall)	.....	$\pm 1/4$ in. [ $\pm 6$ mm]
c	= Depth (overall)	.....	$\pm 1/4$ in. [ $\pm 6$ mm]
c <sub>1</sub>	= Wythe Thickness	.....	$\pm 3/8$ in. [ $\pm 10$ mm]
d	= Variation from Specified Plan End Squareness or Skew ..	$\pm 1/8$ in. per 12 in. width, $\pm 1/2$ in. maximum .....[ $\pm 3$ mm per 300 mm width, $\pm 13$ mm maximum]	
e	= Variation from Specified Elevation End Squareness or Skew.....	$\pm 1/8$ in. per 12 in. [ $\pm 3$ mm per 300 mm]	
f	= Sweep	.....	$\pm 1/8$ in. per 20 ft., $\pm 3/8$ in. maximum .....[ $\pm 3$ mm per 6 m, $\pm 10$ mm maximum]
h	= Local Smoothness of any Surface	.....	.....1/4 in. in 10 ft. [6 mm in 3 m]
i	= Bow	.....	Length/360 maximum
i <sub>1</sub>	= Differential Bowing Between Adjacent Panels of the Same Design	.....	1/2 in. [13 mm]
j	= Warp	.....	1/16 in. per foot [1.5 mm per 300 mm] of distance from adjacent corner
k <sub>1</sub>	= Location of Strand Perpendicular to Plane of Panel	.....	$\pm 1/4$ in. [ $\pm 6$ mm]
k <sub>2</sub>	= Location of Strand Parallel to Plane of Panel	.....	$\pm 1$ in [ $\pm 25$ mm]
l <sub>1</sub>	= Location of Embedment	.....	$\pm 1$ in. [ $\pm 13$ mm]
l <sub>2</sub>	= Tipping and Flushness of Embedment	.....	$\pm 1/4$ in. [ $\pm 6$ mm]
l <sub>3</sub>	= Concrete Surface Between Embedments to Receive Continuous Ledger, Relative to Plane of Embedments	.....	- 1/4 in., + 0 in. [- 6 mm, + 0 mm]
n <sub>1</sub>	= Location of Blockout	.....	$\pm 1$ in. [ $\pm 25$ mm]
n <sub>2</sub>	= Size of Blockouts	.....	$\pm 1/2$ in. [ $\pm 13$ mm]
p	= Location of Inserts for Structural Connections	.....	$\pm 1/2$ in. [ $\pm 13$ mm]

q <sub>1</sub>	= Location of Handling Device Parallel to Length of Panel	.....	$\pm 6$ in. [ $\pm 150$ mm]
q <sub>2</sub>	= Location of Handling Device Transverse to Length of Panel	.....	$\pm 1$ in. [ $\pm 25$ mm]
r <sub>1</sub>	= Location of Haunch Bearing Elevation from End of Panel	.....	$\pm 1/4$ in. [ $\pm 6$ mm]
r <sub>2</sub>	= Transverse Distance Between Haunches	.....	$\pm 1/4$ in. [ $\pm 6$ mm]
r <sub>3</sub>	= Variation from Specified Haunch Bearing Surface Slope	.....	$\pm 1/8$ in. per 18 in., 1/4 in. maximum ..... [ $\pm 3$ mm per 450 mm, 6 mm maximum]
t <sub>1</sub>	= Size of Architectural Feature	.....	$\pm 1/8$ in. [ $\pm 3$ mm]
t <sub>2</sub>	= Location of Architectural Feature	.....	$\pm 1/8$ in. [ $\pm 3$ mm]
w	= Location of Flashing Reglet	.....	$\pm 1/4$ in. [ $\pm 6$ mm]

See pages B.1 through B.4 for additional information and explanation of tolerance requirements for camber, bowing, warping, sweep and local smoothness.

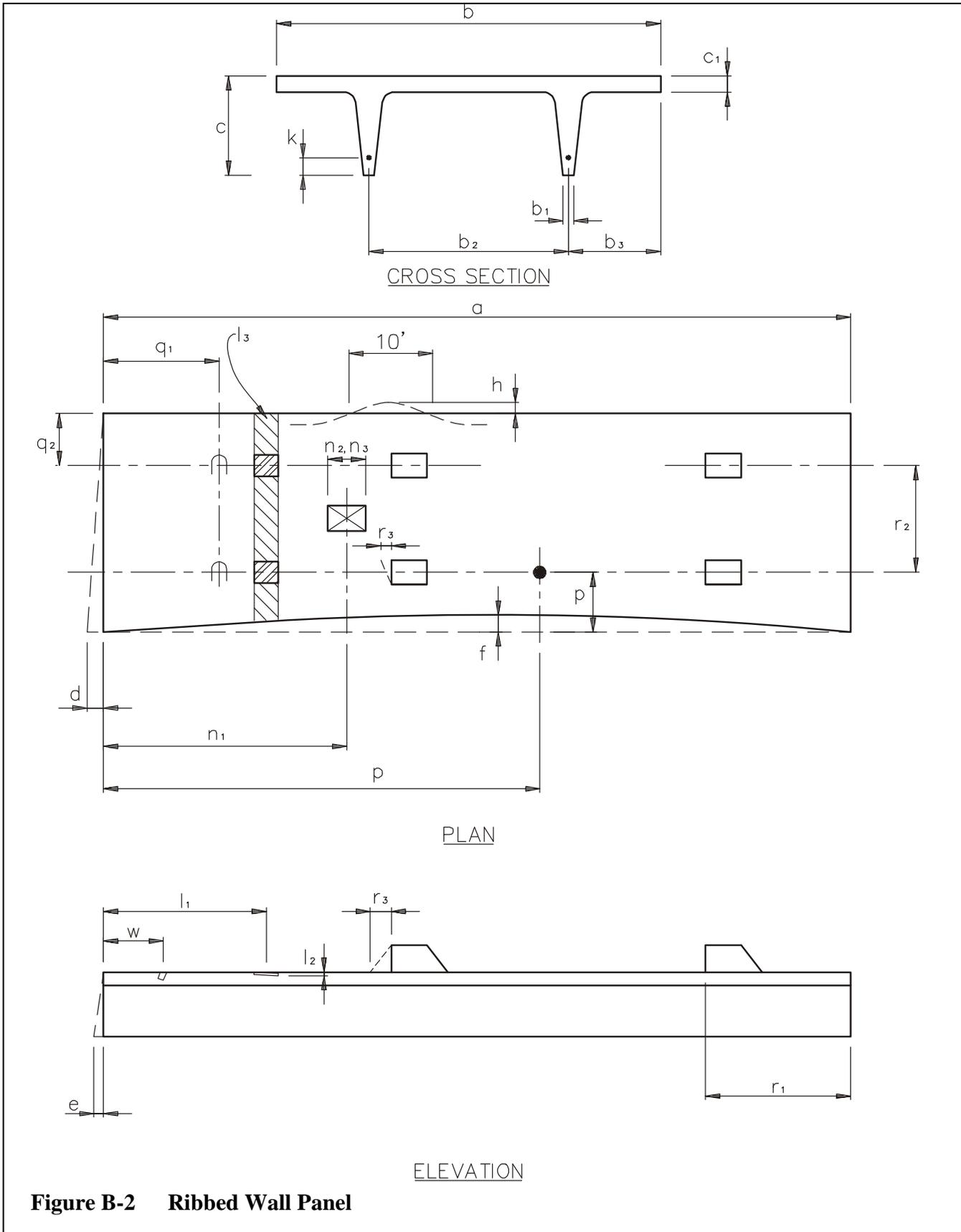


Figure B-2 Ribbed Wall Panel

## APPENDIX B

## Product Dimensional Tolerances

### B-2 Ribbed Wall Panel

a = Length .....	$\pm 1/2$ in. [ $\pm 13$ mm]	n <sub>1</sub> = Location of Blockout .....	$\pm 1$ in. [ $\pm 25$ mm]
b = Width (overall) .....	$\pm 1/4$ in. [ $\pm 6$ mm]	n <sub>2</sub> = Size of Rough Opening .....	$\pm 1$ in. [ $\pm 25$ mm]
b <sub>1</sub> = Stem Width .....	$\pm 1/8$ in. [ $\pm 3$ mm]	n <sub>3</sub> = Size of Finished Opening .....	$\pm 1/2$ in. [ $\pm 13$ mm]
b <sub>2</sub> = Distance Between Stems .....	$\pm 1/8$ in. [ $\pm 3$ mm]	p = Location of Inserts for Structural Sonnections .....	$\pm 1/2$ in. [ $\pm 13$ mm]
b <sub>3</sub> = Stem to Edge of Top Flange .....	$\pm 1/8$ in. [ $\pm 3$ mm]	q <sub>1</sub> = Location of Handling Device Parallel to Length of Panel .....	$\pm 6$ in. [ $\pm 150$ mm]
c = Depth (overall) .....	$\pm 1/4$ in. [ $\pm 6$ mm]	q <sub>2</sub> = Location of Handling Device Transverse to Length of Panel .....	$\pm 1$ in. [ $\pm 25$ mm]
c <sub>1</sub> = Flange Depth ...	+ 1/4 in., - 1/8 in. [+ 6 mm, - 3 mm]	r <sub>1</sub> = Location of Haunch Bearing Elevation from End of Panel .....	$\pm 1/4$ in. [ $\pm 6$ mm]
d = Variation from Specified Plan End Squareness or Skew ..	$\pm 1/8$ in. per 12 in. width, $\pm 1/2$ in. maximum .....[ $\pm 3$ mm per 300 mm width, $\pm 13$ mm maximum]	r <sub>2</sub> = Transverse Distance Between Haunches .....	$\pm 1/4$ in. [ $\pm 6$ mm]
e = Variation from Specified Elevation End Squareness or Skew.....	$\pm 1/8$ in. per 12 in. [ $\pm 3$ mm per 300 mm]	r <sub>3</sub> = Variation from Specified Haunch Bearing Surface Slope .....	$\pm 1/8$ in. per 18 in., 1/4 in. maximum ..... [ $\pm 3$ mm per 450 mm, 6 mm maximum]
f = Sweep, for Member Length:		w = Location of Flashing Reglet .....	$\pm 1/4$ in. [ $\pm 6$ mm]
up to 40 ft. [12 m] .....	$\pm 1/4$ in. [ $\pm 6$ mm]		
40 ft. [12 m] or greater .....	$\pm 3/8$ in. [ $\pm 10$ mm]		
h = Local Smoothness of any surface.....	.....1/4 in. in 10 ft. [6 mm in 3 m]		
i = Bow .....	Length/360 maximum		
i <sub>1</sub> = Differential Bowing Between Adjacent Panels of the Same Design .....	1/2 in. [13 mm]		
j = Warp .....	1/16 in. per foot [1.5 mm per 300 mm]		
k = Location of Strand .....	$\pm 1/4$ in. [ $\pm 6$ mm]		
l <sub>1</sub> = Location of Embedment .....	$\pm 1$ in. [ $\pm 25$ mm]		
l <sub>2</sub> = Tipping and Flushness of Embedment .....	$\pm 1/4$ in. [ $\pm 6$ mm]		
l <sub>3</sub> = Concrete Surface Between Embedments to Receive Continuous Ledger, Relative to Plane of Embedments .....	- 1/4 in., + 0 in. [- 6 mm, + 0 mm]		

See pages B.1 through B.4 for additional information and explanation of tolerance requirements for camber, bowing, warping, sweep and local smoothness.

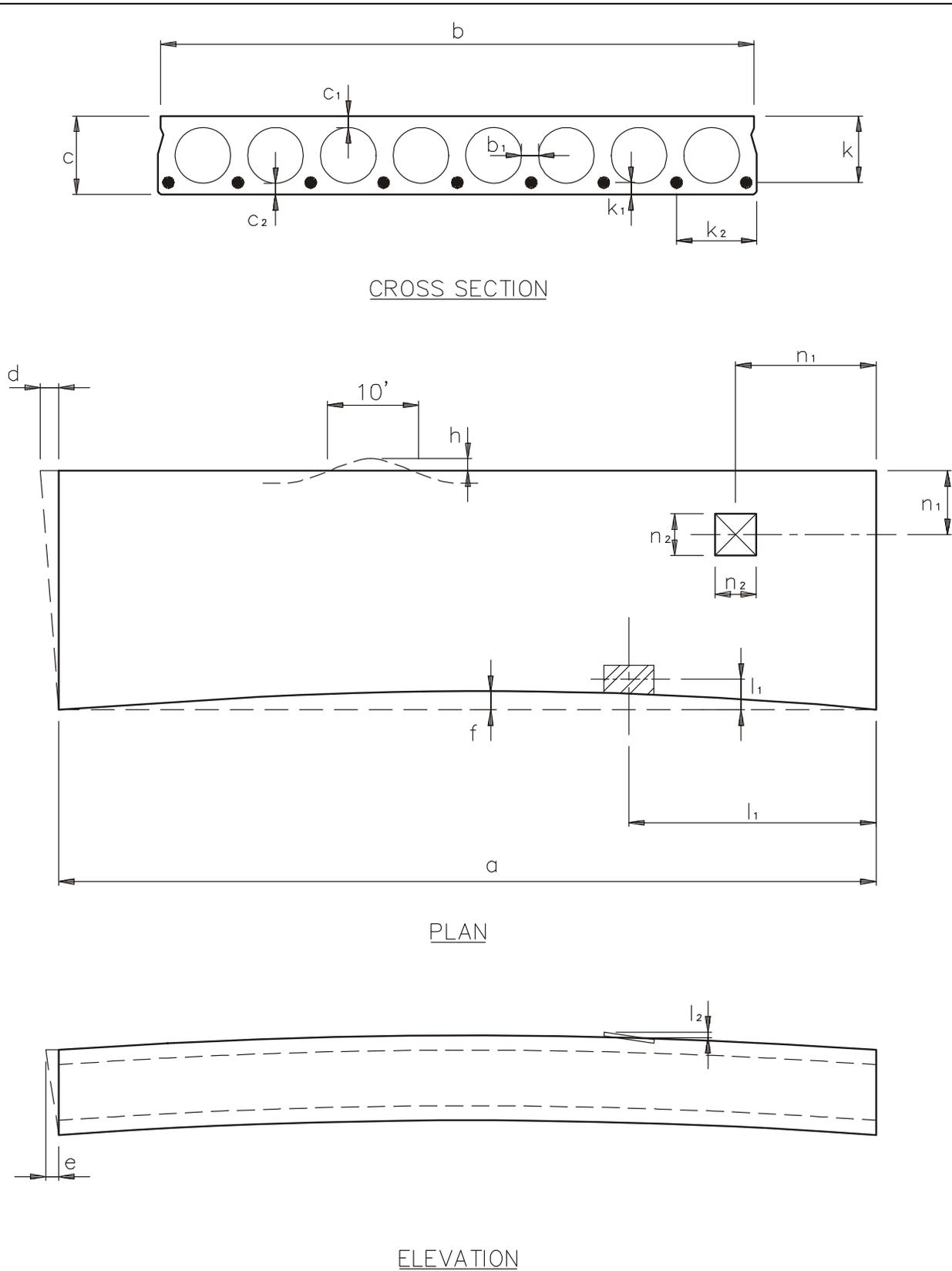


Figure B-3 Hollow-Core Wall Panel

## APPENDIX B

## Product Dimensional Tolerances

### B-3 Hollow-Core Wall Panel

a = Length .....  $\pm 1/2$  in. [ $\pm 13$  mm]

b = Width (overall) .....  $\pm 1/4$  in. [ $\pm 6$  mm]

b<sub>1</sub> = Web Width

The total web width defined by the sum of the actual measured values of “b<sub>1</sub>” shall not be less than 85 percent of the sum of the nominal web widths “b<sub>1, nominal</sub>”

c = Depth (overall) .....  $\pm 1/4$  in. [ $\pm 6$  mm]

c<sub>1</sub> = Top Flange Depth

Top flange area defined by the actual measured values of average “c<sub>1</sub>” x “b” shall not be less than 85 percent of the nominal area calculated by “c<sub>1, nominal</sub>” x “b<sub>nominal</sub>”

c<sub>2</sub> = Bottom Flange Depth

Bottom flange area defined by the actual measured values of average “c<sub>2</sub>” x “b” shall not be less than 85 percent of the nominal area calculated by “c<sub>2, nominal</sub>” x “b<sub>nominal</sub>”

d = Variation From Specified Plan End Squareness or Skew .....  $\pm 1/2$  in. [ $\pm 13$  mm]

e = Variation From Specified Elevation End Squareness or Skew .....  $\pm 1/8$  in. per 12 in. [ $\pm 3$  mm per 300 mm]

f = Sweep .....  $\pm 3/8$  in. [ $\pm 10$  mm]

h = Local Smoothness of Any Surface ..... 1/4 in. in 10 ft. [6 mm in 3 m]

i = Bow ..... Length/360 maximum

i<sub>1</sub> = Differential Bowing Between Adjacent Panels of the Same Design ..... 1/2 in. [13 mm]

j = Warp ..... 1/16 in. per foot [1.5 mm per 300 mm]

k = Center of Gravity (CG) of Strand Group .....  $\pm 1/4$  in. [ $\pm 6$  mm]

k<sub>1</sub> = Location of Strand Perpendicular to Plane of Panel .....  $\pm 1/2$  in. [ $\pm 13$  mm]  
minimum cover = 3/4 in. [19 mm]

k<sub>2</sub> = Location of Strand Parallel to Plane of Panel .....  $\pm 3/4$  in. [ $\pm 19$  mm]  
minimum cover = 3/4 in. [19 mm]

l<sub>1</sub> = Location of Embedment † .....  $\pm 1$  in. [ $\pm 25$  mm]

l<sub>2</sub> = Tipping and Flushness of Embedment .....  $\pm 1/4$  in. [ $\pm 6$  mm]

n<sub>1</sub> = Location of Blockout .....  $\pm 1$  in. [ $\pm 25$  mm]

n<sub>2</sub> = Size of Blockouts .....  $\pm 1/2$  in. [ $\pm 13$  mm]

x = Weight

Actual measured value shall not exceed 110 percent of the nominal published unit weight used in the design.

† Some hollow-core production systems do not permit the incorporation of embedments. Contact local producers for suitable alternate details if embedments are not practical.

See pages B.1 through B.4 for additional information and explanation of tolerance requirements for camber, bowing, warping, sweep and local smoothness.

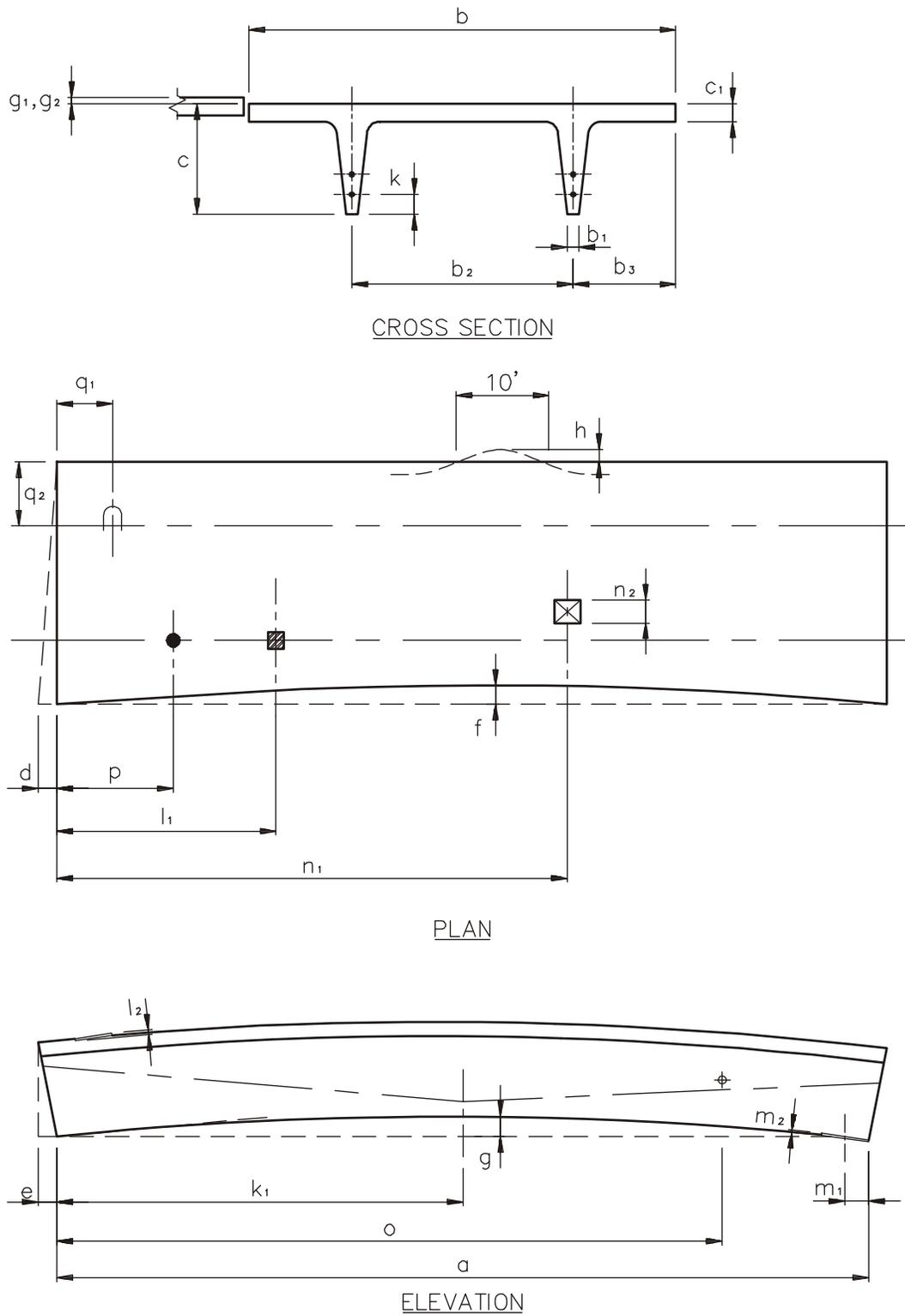


Figure B-4 Double Tee (Untopped and Pretopped)

## APPENDIX B

## Product Dimensional Tolerances

### B-4 Double Tee (Untopped and Pretopped)

a = Length .....	$\pm 1$ in. [ $\pm 25$ mm]	k = Location of Strand	
b = Width (overall) .....	$\pm 1/4$ in. [ $\pm 6$ mm]	individual .....	$\pm 1/4$ in. [ $\pm 6$ mm]
b <sub>1</sub> = Stem Width .....	$\pm 1/8$ in. [ $\pm 3$ mm]	bundled .....	$\pm 1/2$ in. [ $\pm 13$ mm]
b <sub>2</sub> = Distance Between Stems .....	$\pm 1/4$ in. [ $\pm 6$ mm]	k <sub>1</sub> = Location of Harp Points for Harped Strands from Design Location .....	$\pm 20$ in [ $\pm 510$ mm]
b <sub>3</sub> = Stem to Edge of Top Flange .....	$\pm 1/4$ in. [ $\pm 6$ mm]	l <sub>1</sub> = Location of Embedment .....	$\pm 1$ in. [ $\pm 25$ mm]
c = Depth (overall) .....	$\pm 1/4$ in. [ $\pm 6$ mm]	l <sub>2</sub> = Tipping and Flushness of Embedment .....	$\pm 1/4$ in. [ $\pm 6$ mm]
c <sub>1</sub> = Flange Thickness .....	+ 1/4 in., - 1/8 in. .....[+ 6 mm, - 3 mm]	m <sub>1</sub> = Location of Bearing Assembly ..	$\pm 1/2$ in. [ $\pm 13$ mm]
d = Variation From Specified Plan End Squareness or Skew ..	$\pm 1/8$ in. per 12 in. width, $\pm 1/2$ in. maximum .....[ $\pm 3$ mm per 300 mm width, $\pm 13$ mm maximum]	m <sub>2</sub> = Tipping and Flushness of Bearing Assembly .....	$\pm 1/8$ in. [ $\pm 3$ mm]
e = Variation From Specified Elevation End Squareness or Skew		n <sub>1</sub> = Location of Blockout .....	$\pm 1$ in. [ $\pm 25$ mm]
greater than 24 in. [600 mm] depth .....	$\pm 1/8$ in. per 12 in., $\pm 1/2$ in. maximum ..... [ $\pm 3$ mm per 300 mm, $\pm 13$ mm maximum]	n <sub>2</sub> = Size of Blockouts .....	$\pm 1/2$ in. [ $\pm 13$ mm]
24 in. [600 mm] or less depth .....	$\pm 1/4$ in. [ $\pm 6$ mm]	o = Location of Sleeves Cast in Stems, in Both Horizontal and Vertical Plane .....	$\pm 1$ in. [ $\pm 25$ mm]
f = Sweep, for Member Length:		p = Location of Inserts for Structural Connections .....	$\pm 1/2$ in. [ $\pm 13$ mm]
up to 40 ft. [12 m] .....	$\pm 1/4$ in. [ $\pm 6$ mm]	q <sub>1</sub> = Location of Handling Device Parallel to Length of Member.....	$\pm 6$ in. [ $\pm 150$ mm]
40 to 60 ft. [12 to 18 m] .....	$\pm 3/8$ in. [ $\pm 10$ mm]	q <sub>2</sub> = Location of Handling Device Transverse to Length of Member.....	$\pm 1$ in. [ $\pm 25$ mm]
greater than 60 ft. [18 m] .....	$\pm 1/2$ in. [ $\pm 13$ mm]		
g = Camber Variation from Design Camber .....	$\pm 1/4$ in. per 10 ft., $\pm 3/4$ in. maximum .....[ $\pm 6$ mm per 3 m, $\pm 19$ mm maximum]		
g <sub>1</sub> = Differential Camber between Adjacent Untopped Members of the Same Design to Receive Topping ....	1/4 in. per 10 ft., 3/4 in. maximum ..... [6 mm per 3 m, 19 mm maximum]		
g <sub>2</sub> = Differential Camber Between Adjacent Pretopped Members of the Same Design .....	1/8 in. per 10 ft., 3/8 in. maximum ..... [3 mm per 3 m, 10 mm maximum]		
h = Local Smoothness of Any Surface .....	1/4 in. in 10 ft. [6 mm in 3 m]		

See pages B.1 through B.4 for additional information and explanation of tolerance requirements for camber, harp point location, and local smoothness.

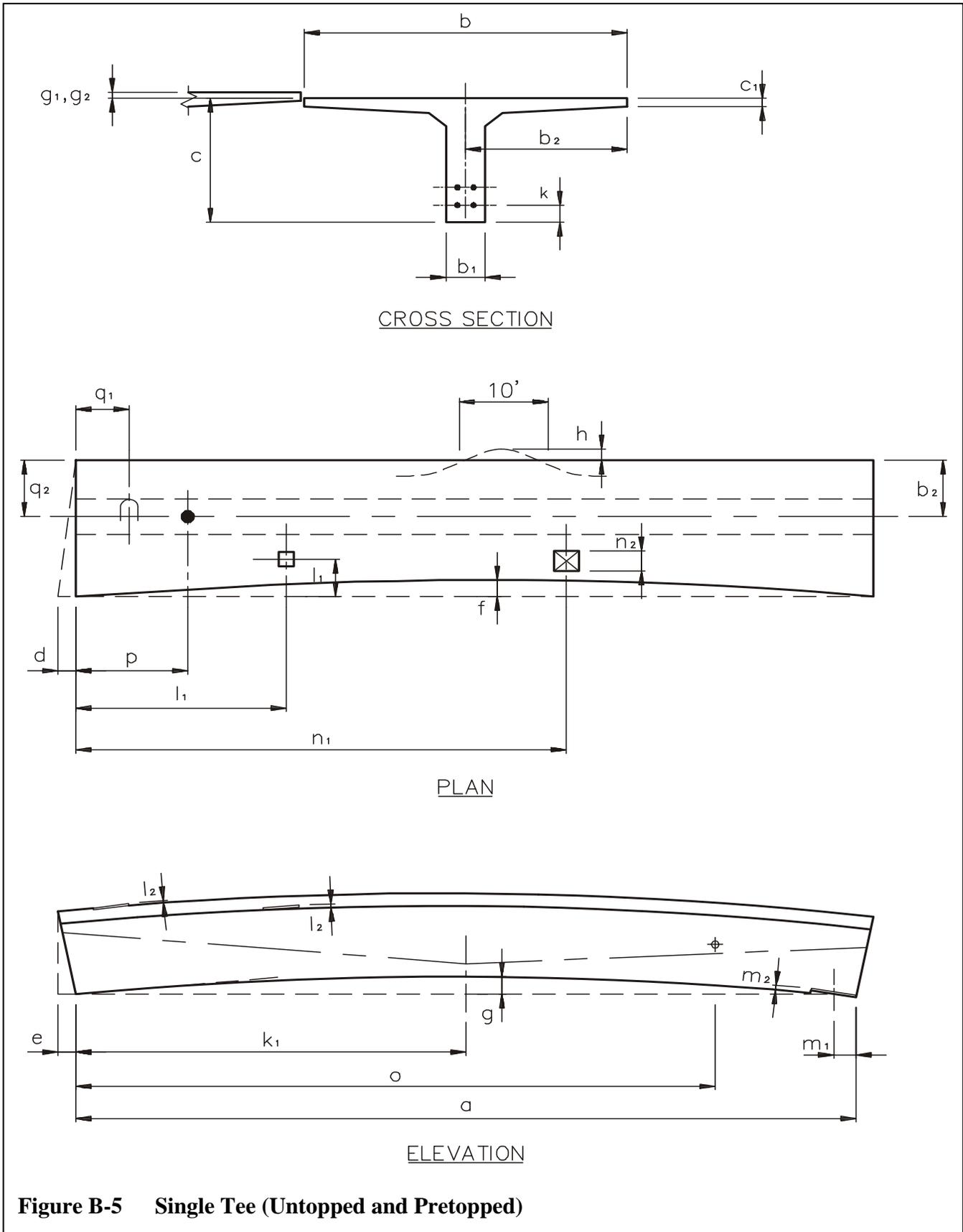


Figure B-5 Single Tee (Untopped and Pretopped)

## APPENDIX B

## Product Dimensional Tolerances

### B-5 Single Tee (Untopped and Pretopped)

a = Length .....	$\pm 1$ in. [ $\pm 25$ mm]	k = Location of Strand	
b = Width (overall) .....	$\pm 1/4$ in. [ $\pm 6$ mm]	individual .....	$\pm 1/4$ in. [ $\pm 6$ mm]
b <sub>1</sub> = Stem Width .....	$\pm 1/4$ in. [ $\pm 6$ mm]	bundled .....	$\pm 1/2$ in. [ $\pm 13$ mm]
b <sub>2</sub> = Stem to Edge of Top Flange .....	$\pm 1/4$ in. [ $\pm 6$ mm]	k <sub>1</sub> = Location of Harp Points for Harped Strands from Design Location .....	$\pm 20$ in [ $\pm 510$ mm]
c = Depth (overall) .....	$\pm 1/4$ in. [ $\pm 6$ mm]	l <sub>1</sub> = Location of Embedment .....	$\pm 1$ in. [ $\pm 25$ mm]
c <sub>1</sub> = Flange Thickness .....	+ 1/4 in., - 1/8 in. .....[+ 6 mm, - 3 mm]	l <sub>2</sub> = Tipping and Flushness of Embedment .....	$\pm 1/4$ in. [ $\pm 6$ mm]
d = Variation From Specified Plan End Squareness or Skew .	$\pm 1/8$ in. per 12 in. width, $\pm 1/2$ in. maximum .....[ $\pm 3$ mm per 300 mm width, $\pm 13$ mm maximum]	m <sub>1</sub> = Location of Bearing Assembly ..	$\pm 1/2$ in. [ $\pm 13$ mm]
e = Variation From Specified Elevation End Squareness or Skew		m <sub>2</sub> = Tipping and Flushness of Bearing Assembly .....	$\pm 1/8$ in. [ $\pm 3$ mm]
greater than 24 in. [600 mm] depth .....	$\pm 1/8$ in. per 12 in., $\pm 1/2$ in. maximum ..... [ $\pm 3$ mm per 300 mm, $\pm 13$ mm maximum]	n <sub>1</sub> = Location of Blockout .....	$\pm 1$ in. [ $\pm 25$ mm]
24 in. [600 mm] or less depth .....	$\pm 1/4$ in. [ $\pm 6$ mm]	n <sub>2</sub> = Size of Blockouts .....	$\pm 1/2$ in. [ $\pm 13$ mm]
f = Sweep, for Member Length:		o = Location of Sleeves Cast in Stems, in Both Horizontal and Vertical Plane .....	$\pm 1$ in. [ $\pm 25$ mm]
up to 40 ft. [12 m] .....	$\pm 1/4$ in. [ $\pm 6$ mm]	p = Location of Inserts for Structural Connections .....	$\pm 1/2$ in. [ $\pm 13$ mm]
40 to 60 ft. [12 to 18 m] .....	$\pm 3/8$ in. [ $\pm 10$ mm]	q <sub>1</sub> = Location of Handling Device Parallel to Length of Member.....	$\pm 6$ in. [ $\pm 150$ mm]
greater than 60 ft. [18 m] .....	$\pm 1/2$ in. [ $\pm 13$ mm]	q <sub>2</sub> = Location of Handling Device Transverse to Length of Member.....	$\pm 1$ in. [ $\pm 25$ mm]
g = Camber Variation from Design Camber .....	$\pm 1/4$ in. per 10 ft., $\pm 3/4$ in. maximum .....[ $\pm 6$ mm per 3 m, $\pm 19$ mm maximum]		
g <sub>1</sub> = Differential Camber Between Adjacent Untopped Members of the Same Design to Receive Topping ....	1/4 in. per 10 ft., 3/4 in. maximum ..... [6 mm per 3 m, 19 mm maximum]		
g <sub>2</sub> = Differential Camber Between Adjacent Pretopped Members of the Same Design .....	1/8 in. per 10 ft., 3/8 in. maximum ..... [3 mm per 3 m, 10 mm maximum]		
h = Local Smoothness of Any Surface .....	1/4 in. in 10 ft. [6 mm in 3 m]		

See pages B.1 through B.4 for additional information and explanation of tolerance requirements for camber, harp point location, and local smoothness.

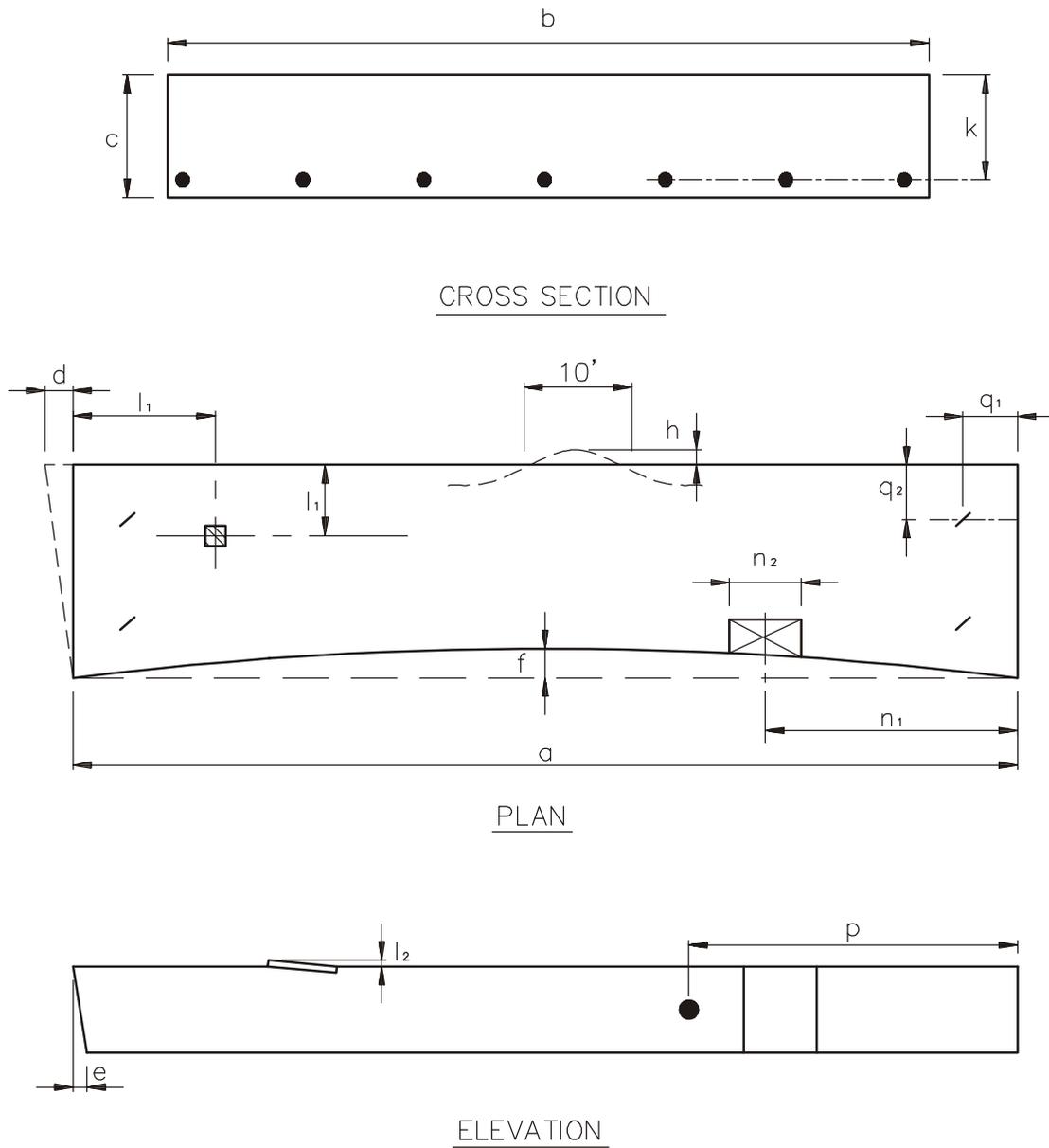


Figure B-6 Solid Flat Slab

**B-6 Solid Flat Slab**

- a = Length .....  $\pm 1/2$  in. [ $\pm 13$  mm]
- b = Width (overall) .....  $\pm 1/4$  in. [ $\pm 6$  mm]
- c = Depth (overall) .....  $\pm 1/4$  in. [ $\pm 6$  mm]
- d = Variation From Specified Plan End Squareness or Skew .  $\pm 1/4$  in. per 12 in. width,  $\pm 1/2$  in. maximum  
..... [ $\pm 3$  mm per 300 mm width,  $\pm 13$  mm maximum]
- e = Variation From Specified Elevation End Squareness or Skew .....  $\pm 1/4$  in. [ $\pm 6$  mm]
- f = Sweep .....  $\pm 3/8$  in. [ $\pm 10$  mm]
- g<sub>1</sub> = Differential Camber Between Adjacent Untopped Members of the Same Design to Receive Topping ....  
.....  $1/4$  in. per 10 ft.,  $3/4$  in. maximum  
..... [6 mm per 3 m, 19 mm maximum]
- g<sub>2</sub> = Differential Camber Between Adjacent Pretopped Members of the Same Design .....  
.....  $1/8$  in. per 10 ft.,  $3/8$  in. maximum  
..... [3 mm per 3 m, 10 mm maximum]
- h = Local Smoothness of Any Surface .....  
.....  $1/4$  in. in 10 ft. [6 mm in 3 m]
- k = Location of Strand .....  $\pm 1/4$  in. [ $\pm 6$  mm]
- l<sub>1</sub> = Location of Embedment .....  $\pm 1$  in. [ $\pm 25$  mm]
- l<sub>2</sub> = Tipping and Flushness of Embedment .....  
.....  $\pm 1/4$  in. [ $\pm 6$  mm]
- n<sub>1</sub> = Location of Blockout .....  $\pm 1$  in. [ $\pm 25$  mm]
- n<sub>2</sub> = Size of Blockouts .....  $\pm 1/2$  in. [ $\pm 13$  mm]
- p = Location of Inserts for Structural Connections .....  
.....  $\pm 1/2$  in. [ $\pm 13$  mm]
- q<sub>1</sub> = Location of Handling Device Parallel to Length of Member .....  $\pm 6$  in. [ $\pm 150$  mm]
- q<sub>2</sub> = Location of Handling Device Transverse to Length of Member .....  $\pm 1$  in. [ $\pm 25$  mm]

See pages B.1 through B.4 for additional information and explanation of tolerance requirements for camber and local smoothness.

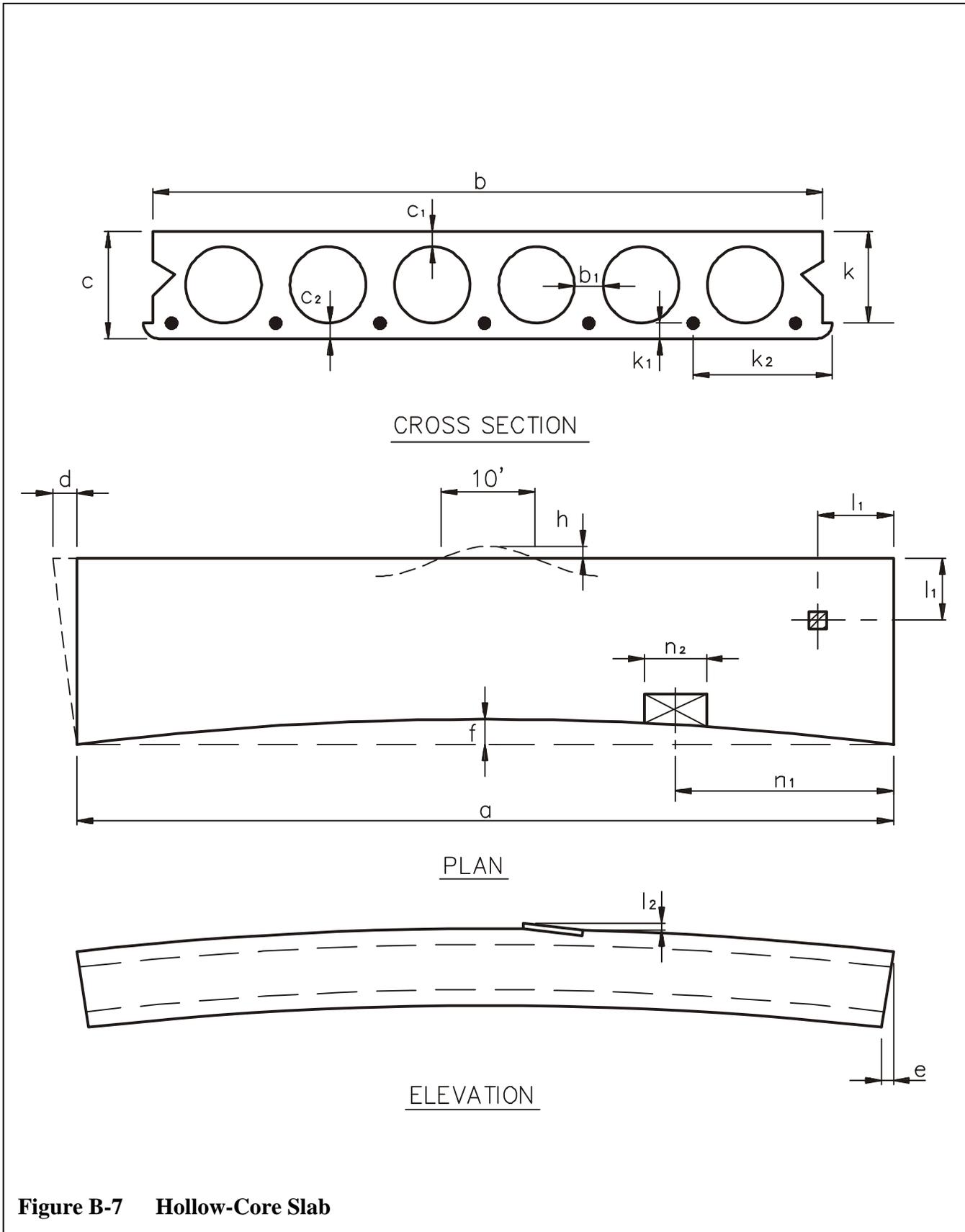


Figure B-7 Hollow-Core Slab

## APPENDIX B

## Product Dimensional Tolerances

### B-7 Hollow-Core Slab

a = Length .....  $\pm 1/2$  in. [ $\pm 13$  mm]

b = Width (overall) .....  $\pm 1/4$  in. [ $\pm 6$  mm]

b<sub>1</sub> = Web Width

The total web width defined by the sum of the actual measured values of “b<sub>1</sub>” shall not be less than 85 percent of the sum of the nominal web widths “b<sub>1, nominal</sub>”

c = Depth (overall) .....  $\pm 1/4$  in. [ $\pm 6$  mm]

c<sub>1</sub> = Top Flange Depth

Top flange area defined by the actual measured values of average “c<sub>1</sub>” x “b” shall not be less than 85 percent of the nominal area calculated by “c<sub>1, nominal</sub>” x “b<sub>nominal</sub>”

c<sub>2</sub> = Bottom Flange Depth

Bottom flange area defined by the actual measured values of average “c<sub>2</sub>” x “b” shall not be less than 85 percent of the nominal area calculated by “c<sub>2, nominal</sub>” x “b<sub>nominal</sub>”

d = Variation From Specified Plan End Squareness or Skew .....  $\pm 1/2$  in. [ $\pm 13$  mm]

e = Variation From Specified Elevation End Squareness or Skew .....  $\pm 1/8$  in. per 12 in.,  $\pm 1/2$  in. maximum  
..... [ $\pm 3$  mm per 300 mm,  $\pm 13$  mm maximum]

f = Sweep .....  $\pm 3/8$  in. [ $\pm 10$  mm]

g – Applications requiring close control of differential camber between adjacent members should be discussed with the producer to determine applicable tolerances.

h = Local Smoothness of any surface.....  
.....  $1/4$  in. in 10 ft. [6 mm in 3 m]

k = Center of Gravity (CG) of Strand Group  
.....  $\pm 1/4$  in. [ $\pm 6$  mm]

k<sub>1</sub> = Location of Strand Perpendicular to Plane of Panel  
.....  $\pm 1/2$  in. [ $\pm 13$  mm]  
minimum cover =  $3/4$  in. [19 mm]

k<sub>2</sub> = Location of Strand Parallel to Plane of Panel  
.....  $\pm 3/4$  in. [ $\pm 19$  mm]  
minimum cover =  $3/4$  in. [19 mm]

l<sub>1</sub> = Location of Embedment † .....  $\pm 2$  in. [ $\pm 50$  mm]

l<sub>2</sub> = Tipping and Flushness of Embedment .....  
.....  $\pm 1/4$  in. [ $\pm 6$  mm]

n<sub>1</sub> = Location of Blockout .....  $\pm 2$  in. [ $\pm 50$  mm]

n<sub>2</sub> = Size of Blockouts .....  $\pm 1/2$  in. [ $\pm 13$  mm]

x = Weight

Actual measured value shall not exceed 110 percent of the nominal published unit weight used in the design.

See pages B.1 through B.4 for additional information and explanation of tolerance requirements for camber, sweep and local smoothness.

† Some hollow-core production systems do not permit the incorporation of embedments. Contact local producers for suitable alternate details if embedments are not practical.

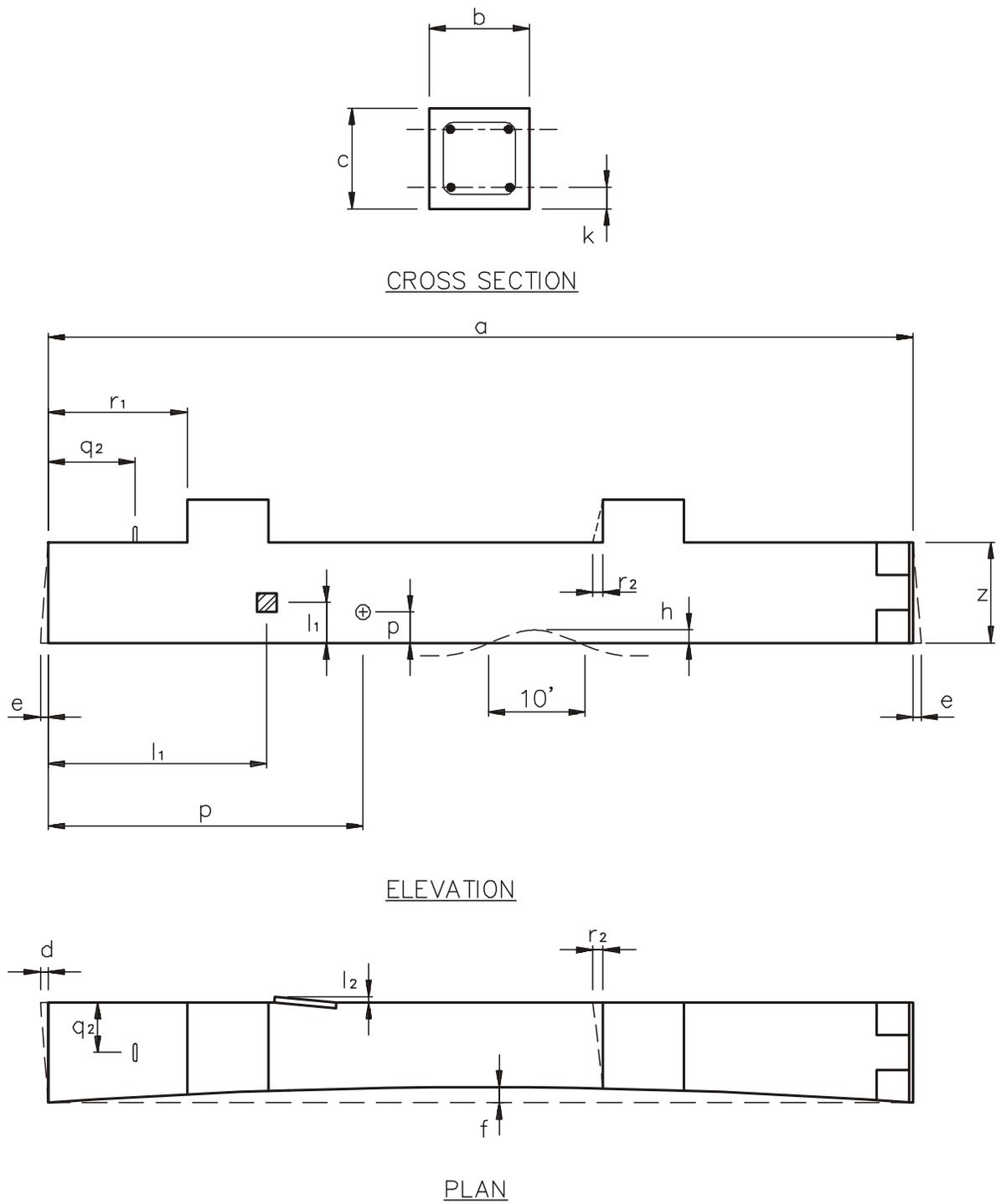


Figure B-8 Column

**B-8 Column**

- a = Length .....  $\pm 1/2$  in. [ $\pm 13$  mm]
- b = Width .....  $\pm 1/4$  in. [ $\pm 6$  mm]
- c = Depth .....  $\pm 1/4$  in. [ $\pm 6$  mm]
- d = Variation From Specified Plan End Squareness or  
Skew .....  $\pm 1/8$  in. per 12 in.,  $\pm 3/8$  in. maximum  
..... [ $\pm 3$  mm per 300 mm,  $\pm 10$  mm maximum]
- e = Variation From Specified Elevation End Squareness  
or Skew .....  $\pm 1/8$  in. per 12 in.,  $\pm 3/8$  in. maximum  
..... [ $\pm 3$  mm per 300 mm,  $\pm 10$  mm maximum]
- f = Sweep .....  $\pm 1/8$  in. per 10 ft.,  $\pm 1/2$  in. maximum  
..... [ $\pm 3$  mm per 3 m,  $\pm 13$  mm maximum]
- h = Local Smoothness of Any Surface .....  
.....  $1/4$  in. in 10 ft. [6 mm in 3 m]
- k = Location of Strand .....  $\pm 1/4$  in. [ $\pm 6$  mm]
- $l_1$  = Location of Embedment .....  $\pm 1$  in. [ $\pm 25$  mm]
- $l_2$  = Tipping and Flushness of Embedment .....  
.....  $\pm 1/4$  in. [ $\pm 6$  mm]
- p = Location of Inserts for Structural Connections .....  
.....  $\pm 1/2$  in. [ $\pm 13$  mm]
- $q_1$  = Location of Handling Device Parallel to Length of  
Member .....  $\pm 6$  in. [ $\pm 150$  mm]
- $q_2$  = Location of Handling Device Transverse to Length of  
Member .....  $\pm 1$  in. [ $\pm 25$  mm]
- $r_1$  = Location of Haunch Bearing Elevation from End  
.....  $\pm 1/4$  in. [ $\pm 6$  mm]
- $r_2$  = Variation from Specified Haunch Bearing Surface  
Slope .....  $\pm 1/8$  in. per 12 in.,  $3/8$  in. maximum  
..... [ $\pm 3$  mm per 300 mm, 10 mm maximum]
- z = Baseplate Overall Dimensions .....  $\pm 1/4$  in. [ $\pm 6$  mm]

See pages B.1 through B.4 for additional information and explanation of tolerance requirements for sweep and local smoothness.

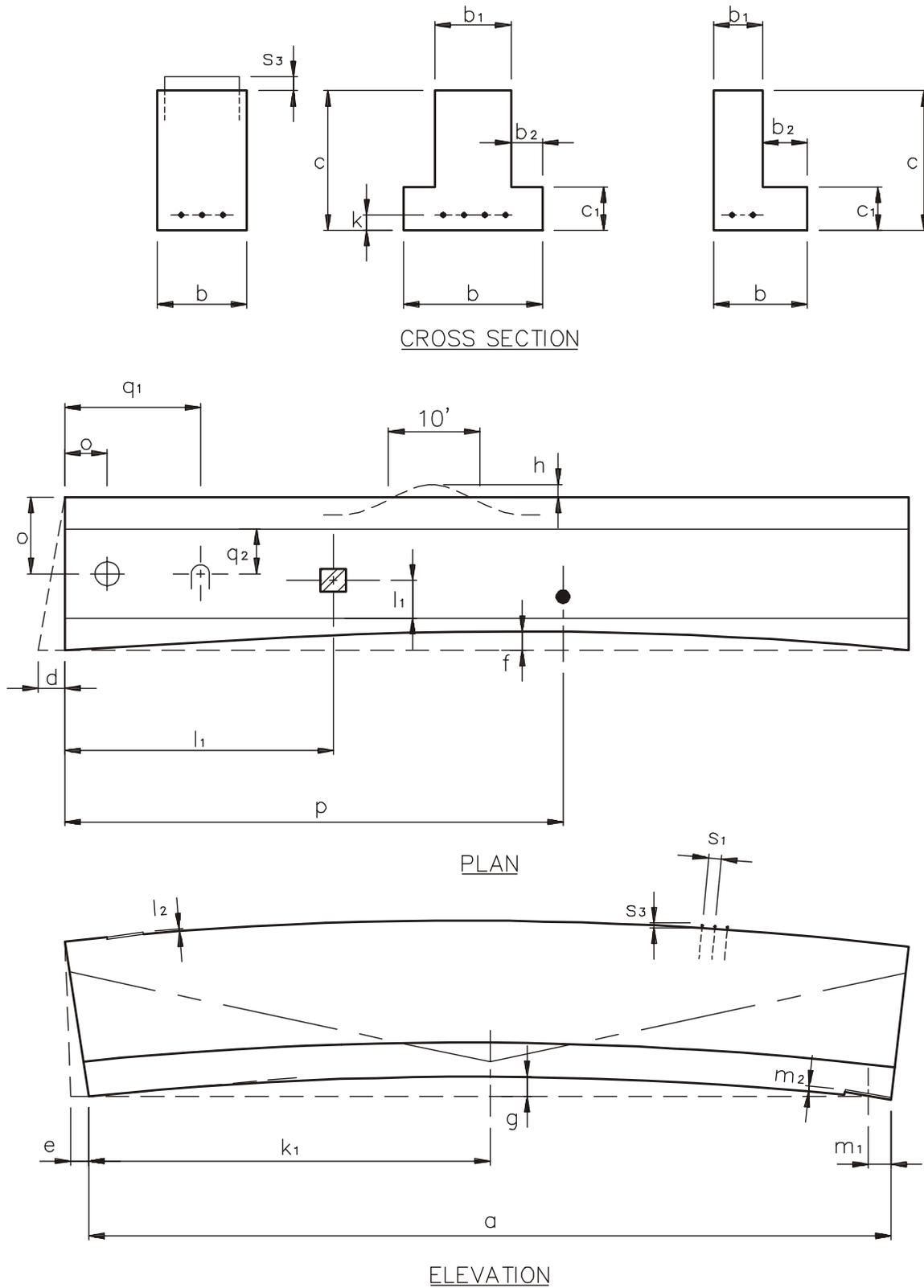


Figure B-9 Building Beam or Spandrel

## APPENDIX B

## Product Dimensional Tolerances

### B-9 Building Beam or Spandrel

a = Length .....	$\pm 3/4$ in. [ $\pm 19$ mm]	$m_1$ = Location of Bearing Assembly ..	$\pm 1/2$ in. [ $\pm 13$ mm]
b = Width (overall) .....	$\pm 1/4$ in. [ $\pm 6$ mm]	$m_2$ = Tipping and Flushness of Bearing Assembly .....	$\pm 1/8$ in. [ $\pm 3$ mm]
$b_1$ = Stem Width .....	$\pm 1/4$ in. [ $\pm 6$ mm]	o = Location of Sleeves Cast in Stems, in Both Horizontal and Vertical Plane .....	$\pm 1$ in. [ $\pm 25$ mm]
$b_2$ = Ledge Width .....	$\pm 1/4$ in. [ $\pm 6$ mm]	p = Location of Inserts for Structural Connections .....	$\pm 1/2$ in. [ $\pm 13$ mm]
c = Depth (overall) .....	$\pm 1/4$ in. [ $\pm 6$ mm]	$q_1$ = Location of Handling Device Parallel to Length of Member .....	$\pm 12$ in. [ $\pm 300$ mm]
$c_1$ = Ledge Depth .....	$\pm 1/4$ in. [ $\pm 6$ mm]	$q_2$ = Location of Handling Device Transverse to Length of Member .....	$\pm 1/2$ in. [ $\pm 13$ mm]
d = Variation From Specified Plan End Squareness or Skew ..... $\pm 1/8$ in. per 12 in. width, $\pm 1/2$ in. maximum ..... [ $\pm 3$ mm per 300 mm width, $\pm 13$ mm maximum]		$s_1$ = Longitudinal Spacing of Stirrups .....	$\pm 2$ in. [ $\pm 50$ mm]
e = Variation From Specified Elevation End Squareness or Skew ..... $\pm 1/8$ in. per 12 in. depth, $\pm 1/2$ in. maximum ..... [ $\pm 3$ mm per 300 mm, $\pm 13$ mm maximum]		$s_2$ = Longitudinal Spacing of Stirrups within Distance "c" from Member Ends .....	$\pm 1$ in. [ $\pm 25$ mm]
f = Sweep, for Member Length:  up to 40 ft. [12 m] .....	$\pm 1/4$ in. [ $\pm 6$ mm]	$s_3$ = Stirrup Projection from Beam Surface .....	+ $1/4$ in., - $1/2$ in. [ $+ 6$ mm, - $13$ mm]
40 to 60 ft. [12 to 18 m] .....	$\pm 1/2$ in. [ $\pm 13$ mm]		
greater than 60 ft. [18 m] .....	$\pm 5/8$ in. [ $\pm 16$ mm]		
g = Camber Variation from Design Camber .....	$\pm 1/8$ in. per 10 ft., $\pm 3/4$ in. maximum ..... [ $\pm 3$ mm per 3 m, $\pm 19$ mm maximum]		
h = Local Smoothness of Any Surface .....	$1/4$ in. in 10 ft. [6 mm in 3 m]		
k = Location of Strand  individual .....	$\pm 1/4$ in. [ $\pm 6$ mm]		
bundled .....	$\pm 1/2$ in. [ $\pm 13$ mm]		
$k_1$ = Location of Harp Points for Harped Strands from Design Location for Member Length  30 ft. [9 m] or less .....	$\pm 6$ in [ $\pm 150$ mm]		
greater than 30 ft. [9 m] .....	$\pm 12$ in [ $\pm 300$ mm]		
$l_1$ = Location of Embedment .....	$\pm 1$ in. [ $\pm 25$ mm]		
$l_2$ = Tipping and Flushness of Embedment .....	$\pm 1/4$ in. [ $\pm 6$ mm]		

See pages B.1 through B.4 for additional information and explanation of tolerance requirements for camber, harp point location, and local smoothness.

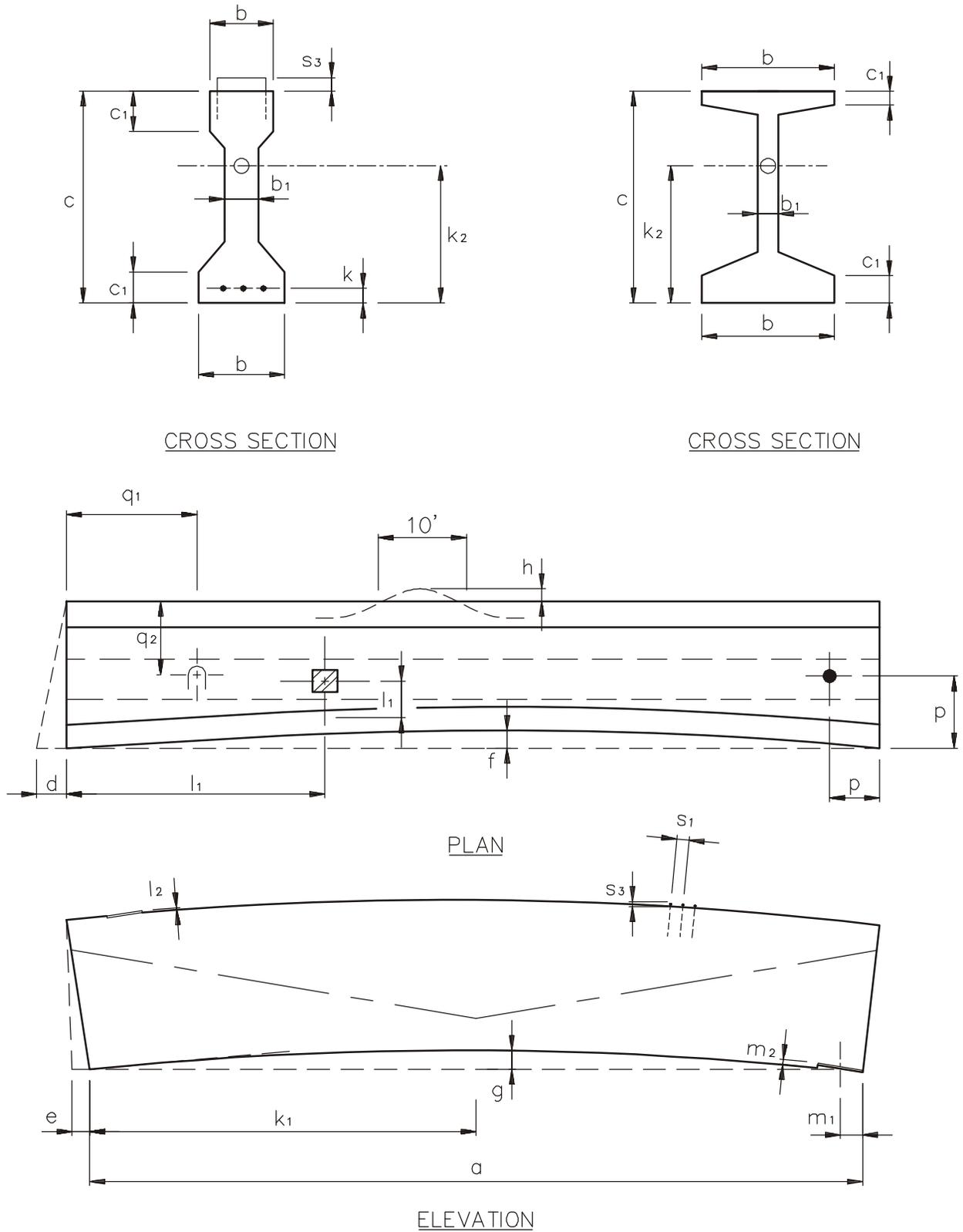


Figure B-10 I-Beam (Girder) or Bulb-Tee Girder

## APPENDIX B

## Product Dimensional Tolerances

### B-10 I-Beam (Girder) or Bulb-Tee Girder

- a = Length ...  $\pm 1/4$  in. per 25 ft. length,  $\pm 1$  in. maximum  
..... [ $\pm 6$  mm per 7.5 m length,  $\pm 25$  mm maximum]
- b = Width (overall) .....  $+ 3/8$  in.,  $- 1/4$  in.  
..... [ $+ 10$  mm,  $- 6$  mm]
- b<sub>1</sub> = Web Width .....  $+ 3/8$  in.,  $- 1/4$  in.  
..... [ $+ 10$  mm,  $- 6$  mm]
- c = Depth (overall) .....  $+ 1/2$  in.,  $- 1/4$  in.  
..... [ $+ 13$  mm,  $- 6$  mm]
- c<sub>1</sub> = Flange Depth .....  $\pm 1/4$  in. [ $\pm 6$  mm]
- d = Variation From Specified Plan End Squareness or Skew  
.....  $\pm 1/8$  in. per 12 in. width,  $\pm 1/2$  in. maximum  
..... [ $\pm 3$  mm per 300 mm width, 13 mm maximum]
- e = Variation From Specified Elevation End Squareness or Skew  
.....  $\pm 3/16$  in. per 12 in. depth,  $\pm 1$  in. maximum  
..... [ $\pm 5$  mm per 300 mm, 25 mm maximum]
- f = Sweep .....  $1/8$  in. per 10 ft. length  
..... [3 mm per 3 m length]
- g = Camber Variation from Design Camber .....  
.....  $\pm 1/8$  in. per 10 ft. [ $\pm 3$  mm per 3 m]  
 $\pm 1/2$  in. [ $\pm 13$  mm] maximum up to 80 ft. [24 m]  
length  
 $\pm 1$  in. [ $\pm 25$  mm] maximum for length greater than  
80 ft. [24 m]
- h = Local Smoothness of Any Surface .....  
.....  $1/4$  in. in 10 ft. [6 mm in 3 m]
- k = Location of Strand <sup>†</sup>
- individual .....  $\pm 1/4$  in. [ $\pm 6$  mm]  
bundled .....  $\pm 1/2$  in. [ $\pm 13$  mm]
- k<sub>1</sub> = Location of Harp Points for Harped Strands from Design Location .....  $\pm 20$  in [ $\pm 510$  mm]
- k<sub>2</sub> = Location of Post-Tensioning Duct  
.....  $\pm 1/4$  in. [ $\pm 6$  mm]
- l<sub>1</sub> = Location of Embedment .....  $\pm 1$  in. [ $\pm 25$  mm]
- l<sub>2</sub> = Tipping and Flushness of Embedment .....  
.....  $\pm 1/4$  in. [ $\pm 6$  mm]

- m<sub>1</sub> = Location of Bearing Assembly ..  $\pm 5/8$  in. [ $\pm 16$  mm]
- m<sub>2</sub> = Tipping and Flushness of Bearing Assembly .....  
.....  $\pm 1/8$  in. [ $\pm 3$  mm]
- p = Location of Inserts for Structural Connections .....  
.....  $\pm 1/2$  in. [ $\pm 13$  mm]
- q<sub>1</sub> = Location of Handling Device Parallel to Length of Member .....  
.....  $\pm 6$  in. [ $\pm 150$  mm]
- q<sub>2</sub> = Location of Handling Device Transverse to Length of Member .....  
.....  $\pm 1$  in. [ $\pm 25$  mm]
- s<sub>1</sub> = Longitudinal Spacing of Stirrups .....  $\pm 2$  in. [ $\pm 50$  mm]
- s<sub>2</sub> = Longitudinal Spacing of Stirrups within Distance “c” from Member Ends .....  
.....  $\pm 1$  in. [ $\pm 25$  mm]
- s<sub>3</sub> = Stirrup Projection from Beam Surface  
.....  $+ 1/4$  in.,  $- 1/2$  in. [ $+ 6$  mm,  $- 13$  mm]

See pages B.1 through B.4 for additional information and explanation of tolerance requirements for camber, harp point location, and local smoothness.

<sup>†</sup> The location of harped strand at the end of the beam may be controlled to  $\pm 1/2$  in. [ $\pm 13$  mm] providing that calculations show that such a variation will not result in unacceptable stresses at any design load condition.

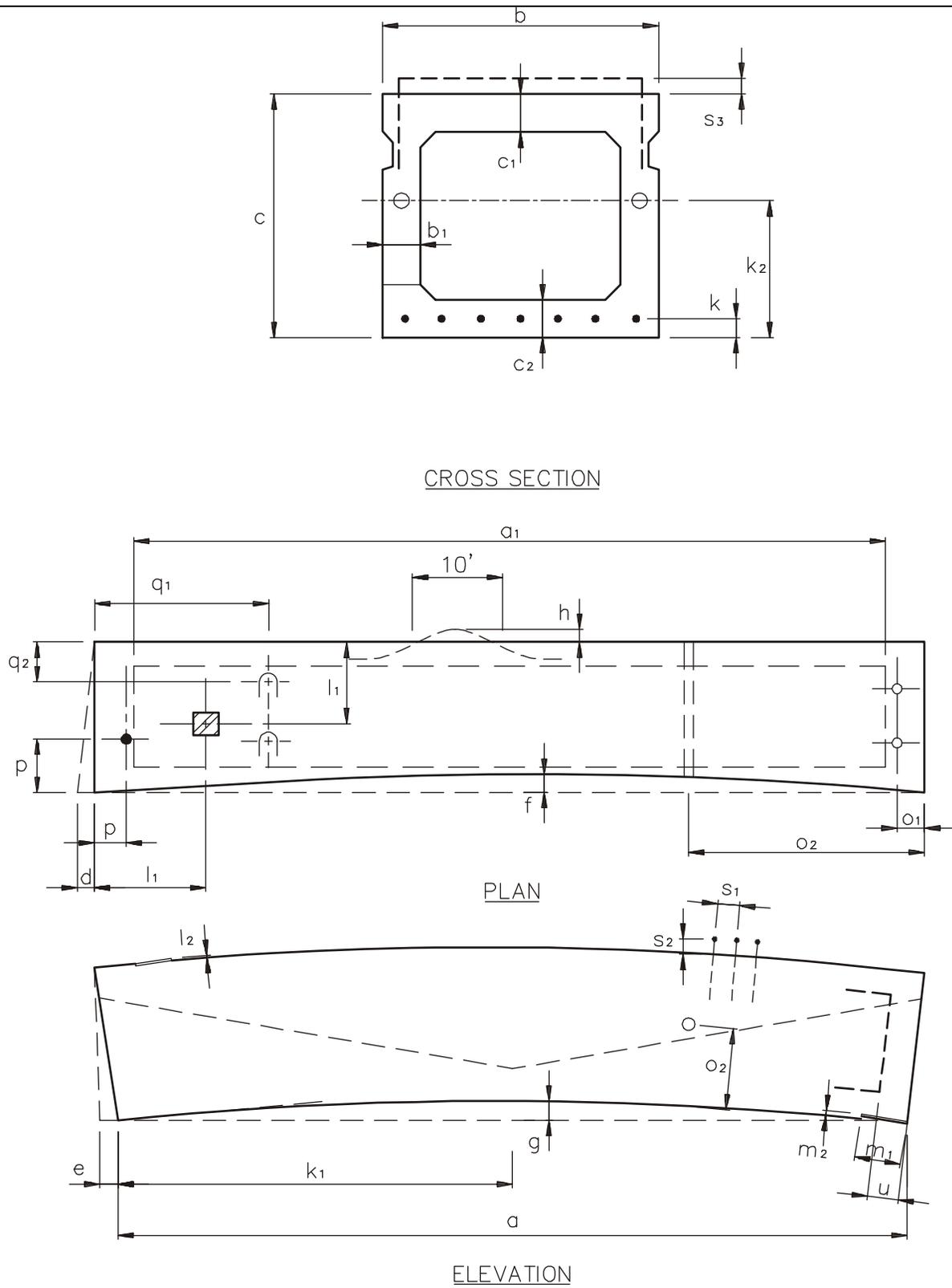


Figure B-11 Box Beam

## APPENDIX B

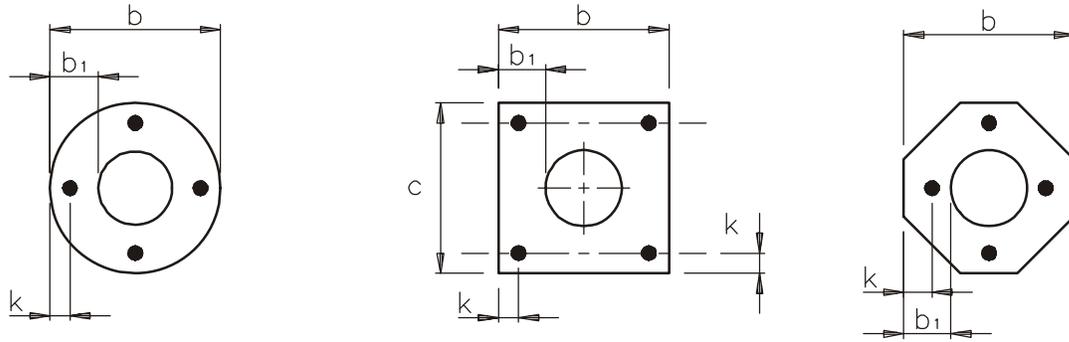
## Product Dimensional Tolerances

### B-11 Box Beam

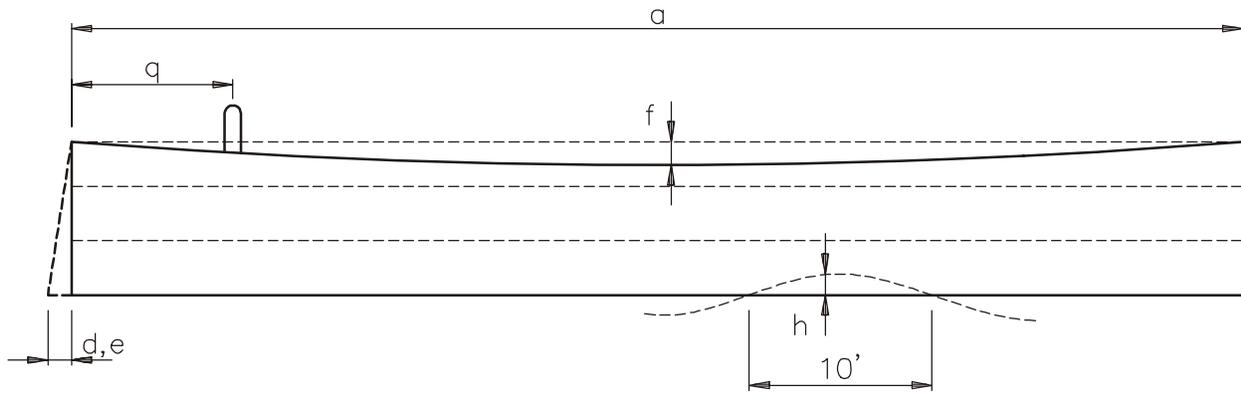
a = Length .....	$\pm 3/4$ in. [ $\pm 19$ ]	$l_1$ = Location of Embedment .....	$\pm 1$ in. [ $\pm 25$ mm]
$a_1$ = Length of Void Form .....	$+ 1$ in., $- 6$ in. [ $+ 25$ mm, $- 150$ mm]	$l_2$ = Tipping and Flushness of Embedment .....	$\pm 1/4$ in. [ $\pm 6$ mm]
b = Width (overall) .....	$\pm 1/4$ in. [ $\pm 6$ mm]	$m_1$ = Location of Bearing Assembly ..	$\pm 5/8$ in. [ $\pm 16$ mm]
$b_1$ = Web Width .....	$\pm 3/8$ in. [ $\pm 10$ mm]	$m_2$ = Tipping and Flushness of Beam Seat Bearing Surface .....	$\pm 1/8$ in. [ $\pm 3$ mm]
c = Depth (overall) .....	$\pm 1/4$ in. [ $\pm 6$ mm]	$o_1$ = Location of Sleeve at Connection to Support .....	$\pm 5/8$ in. [ $\pm 16$ mm]
$c_1$ = Top Flange Depth .....	$\pm 1/2$ in. [ $\pm 13$ mm]	$o_2$ = Location of Tie-Rod Sleeve	
$c_2$ = Bottom Flange Depth .....	$+ 1/2$ in., $- 1/8$ in. [ $+ 13$ mm, $- 3$ mm]	horizontal .....	$\pm 1/2$ in. [ $\pm 13$ mm]
d = Variation From Specified Plan End Squareness or Skew .....	$\pm 1/8$ in. per 12 in. width, $\pm 1/2$ in. maximum	vertical .....	$\pm 3/8$ in. [ $\pm 10$ mm]
.....	[ $\pm 3$ mm per 300 mm width, $\pm 13$ mm maximum]	p = Location of Inserts for Structural Connections .....	$\pm 1/2$ in. [ $\pm 13$ mm]
e = Variation From Specified Elevation End Squareness or Skew .....	$\pm 1/2$ in. [ $\pm 13$ mm]	$q_1$ = Location of Handling Device Parallel to Length of Member .....	$\pm 6$ in. [ $\pm 150$ mm]
f = Sweep, for Member Length:		$q_2$ = Location of Handling Device Transverse to Length of Member .....	$\pm 1$ in. [ $\pm 25$ mm]
up to 40 ft. [12 m] .....	$\pm 1/4$ in. [ $\pm 6$ mm]	$s_1$ = Longitudinal Spacing of Stirrups ...	$\pm 1$ in. [ $\pm 25$ mm]
40 to 60 ft. [12 to 18 m] .....	$\pm 3/8$ in. [ $\pm 10$ mm]	$s_2$ = Stirrup Projection from Beam Surface .....	$+ 1/4$ in., $- 1/2$ in. [ $+ 6$ mm, $- 13$ mm]
greater than 60 ft. [18 m] .....	$\pm 1/2$ in. [ $\pm 13$ mm]	u = Location of Void	
g = Camber Variation from Design Camber .....	$\pm 1/8$ in. per 10 ft., $\pm 1/2$ in. maximum	relative to design center location .	$\pm 1/2$ in. [ $\pm 13$ mm]
.....	[ $\pm 3$ mm per 3 m, $\pm 13$ mm maximum]	from end of beam ..	$+ 3$ in., $- 1$ in. [ $+ 75$ mm, $- 25$ mm]
$g_1$ = Differential Camber Between Adjacent Members of the Same Design .....	$1/4$ in. per 10 ft., $\pm 3/4$ in. maximum		
.....	[6 mm per 3 m, $\pm 19$ mm maximum]		
h = Local Smoothness of Any Surface .....	$1/4$ in. in 10 ft. [6 mm in 3 m]		
k = Location of Strand <sup>†</sup>			
individual .....	$\pm 1/4$ in. [ $\pm 6$ mm]		
bundled .....	$\pm 1/4$ in. [ $\pm 6$ mm]		
$k_1$ = Location of Harp Points for Harped Strands from Design Location .....	$\pm 20$ in [ $\pm 510$ mm]		
$k_2$ = Location of Post-Tensioning Duct .....	$\pm 1/4$ in. [ $\pm 6$ mm]		

See pages B.1 through B.4 for additional information and explanation of tolerance requirements for camber, harp point location, and local smoothness.

<sup>†</sup> The location of harped strand at the end of the beam may be controlled to  $\pm 1/2$  in. [ $\pm 13$  mm] providing that calculations show that such a variation will not result in unacceptable stresses at any design load condition.



CROSS SECTIONS



SIDE

Figure B-12 Piling (Solid or Hollow)

**B-12 Piling (Solid or Hollow)**

- a = Length † ..... ± 1 in. [± 25 mm]
- b = Width or Diameter ..... ± 3/8 in. [± 10 mm]
- b<sub>1</sub> = Wall Thickness .....  
 ..... + 1/2 in., - 1/4 in. [+ 13 mm, - 6 mm]
- c = Depth ..... ± 3/8 in. [± 10 mm]
- d = Variation From Specified Plan End Squareness or  
 Skew ..... ± 1/4 in. per 12 in., ± 1/2 in. maximum  
 ..... [± 6 mm per 300 mm, ± 13 mm maximum]
- e = Variation From Specified Elevation End Squareness  
 or Skew ..... ± 1/4 in. per 12 in., ± 1/2 in. maximum  
 ..... [± 3 mm per 300 mm, ± 13 mm maximum]
- f = Sweep ..... ± 1/8 in. per 10 ft. [± 3 mm per 3 m]
- h = Local Smoothness of Any Surface .....  
 ..... 1/4 in. in 10 ft. [6 mm in 3 m]
- k = Location of Strand ..... ± 1/4 in. [± 6 mm]
- q = Location of Handling Device ..... ± 6 in. [± 150 mm]
- s = Longitudinal Spacing of Stirrups or Spiral  
 Reinforcement  
 ..... ± 3/4 in. [± 19 mm]
- z = Location of Driving Tip ..... ± 1/2 in. [± 13 mm]

See pages B.1 through B.4 for additional information and explanation of tolerance requirements for sweep and local smoothness.

† Controlling pile length to + 6 in., - 2 in. [+ 150 mm, - 50 mm] is acceptable in most cases.

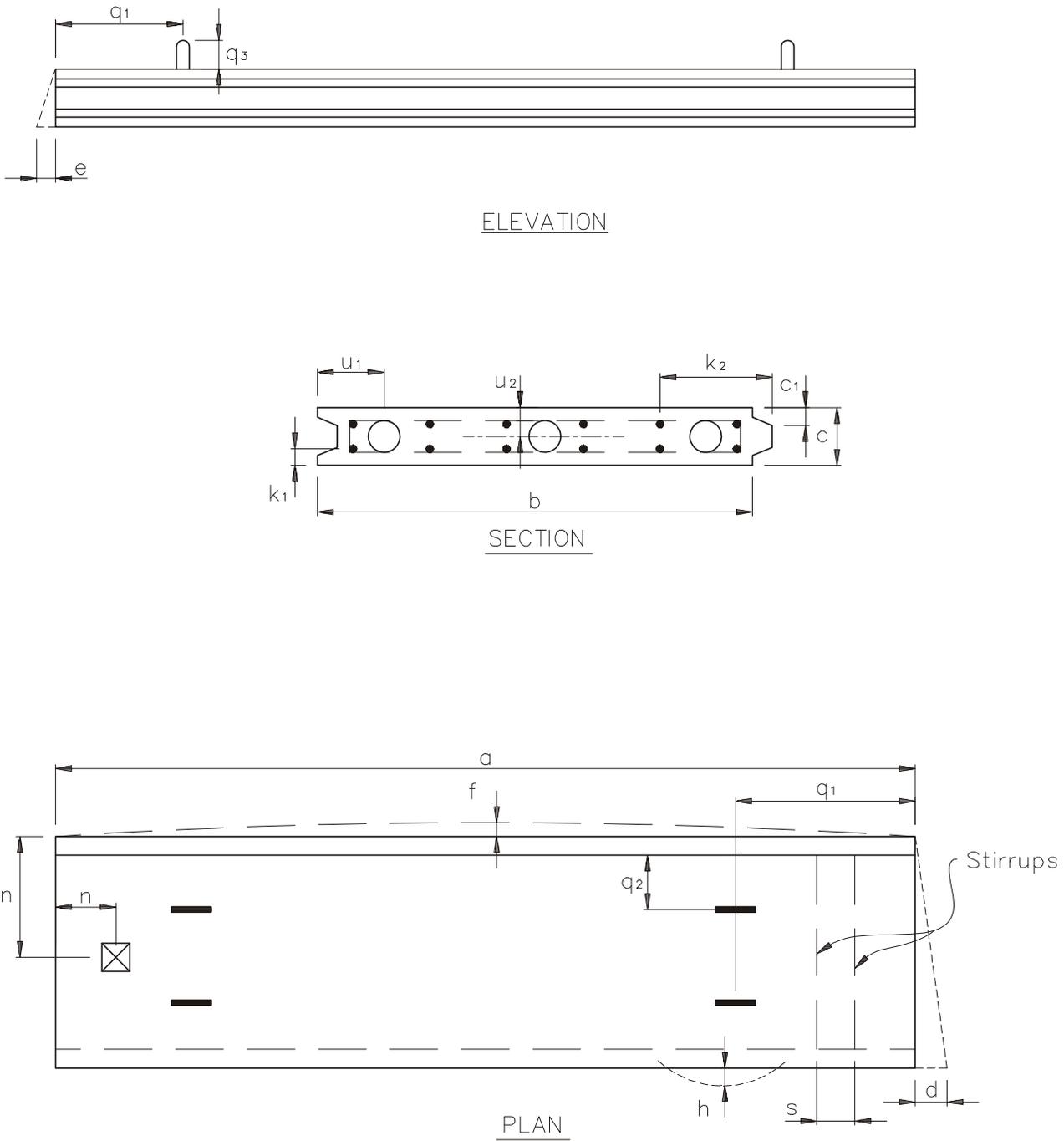


Figure B-13 Sheet Piling

**B-13 Sheet Piling**

- a = Length .....  $\pm 1$  in. [ $\pm 25$  mm]
- b = Width .....  $\pm 3/8$  in. [ $\pm 10$  mm]
- c = Depth .....  $\pm 1/4$  in. [ $\pm 6$  mm]
- c<sub>1</sub> = Flange Depth .....  $\pm 1/2$  in. [ $\pm 13$  mm]
- d = Variation From Specified Plan End Squareness or  
Skew .....  $\pm 1/4$  in. per 10 ft.,  $\pm 1/2$  in. maximum  
..... [ $\pm 6$  mm per 3 m,  $\pm 13$  mm maximum]
- e = Variation From Specified Plan End Squareness or  
Skew .....  $\pm 1/4$  in. [ $\pm 6$  mm]
- f = Sweep .....  $\pm 1/8$  in. per 10 ft. [ $\pm 3$  mm per 3 m]
- h = Local Smoothness of Any Surface .....  
.....  $1/4$  in. in 10 ft. [6 mm in 3 m]
- k<sub>1</sub> = Location of Strand Perpendicular to Plane of Panel  
.....  $\pm 1/4$  in. [ $\pm 6$  mm]
- k<sub>2</sub> = Location of Strand Parallel to Plane of Panel  
.....  $\pm 1$  in. [ $\pm 25$  mm]
- n = Location of Blockout .....  $\pm 1$  in. [ $\pm 25$  mm]
- q<sub>1</sub> = Location of Handling Device Parallel to Length of  
Member .....  $\pm 6$  in. [ $\pm 150$  mm]
- q<sub>2</sub> = Location of Handling Device Transverse to Length of  
Member .....  $\pm 1/2$  in. [ $\pm 13$  mm]
- q<sub>3</sub> = Projection of Handling Device ...  $\pm 1/2$  in. [ $\pm 13$  mm]
- s = Longitudinal Spacing of Stirrups .....  
.....  $\pm 3/4$  in. [ $\pm 19$  mm]
- u<sub>1</sub> = Transverse Location of Voids ....  $\pm 1/2$  in. [ $\pm 13$  mm]
- u<sub>2</sub> = Vertical Location of Voids .....  $\pm 1/4$  in. [ $\pm 6$  mm]
- u<sub>3</sub> = Longitudinal Location of Voids .  $\pm 1/2$  in. [ $\pm 13$  mm]

See pages B.1 through B.4 for additional information and explanation of tolerance requirements for sweep and local smoothness.

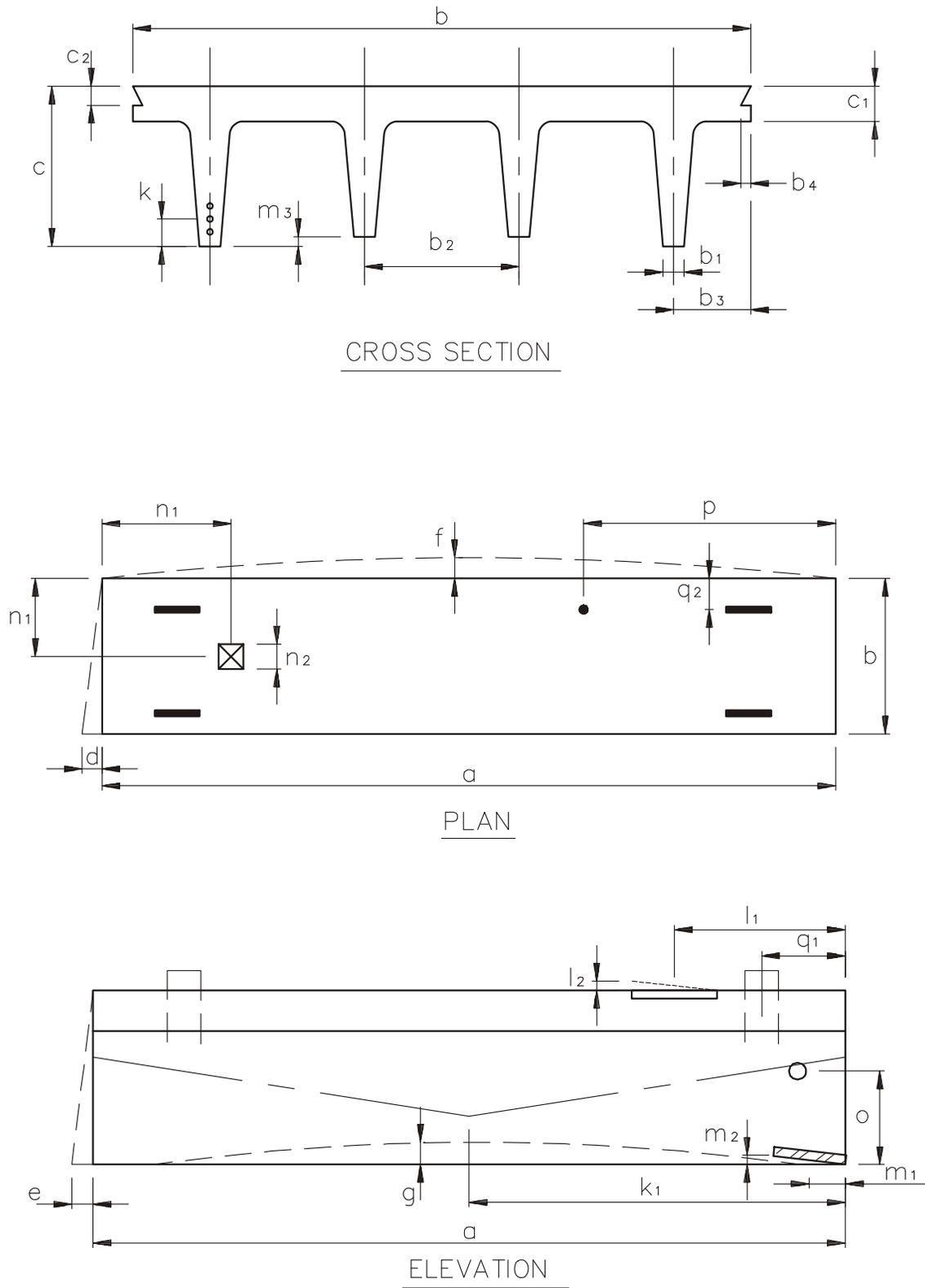


Figure B-14 Multi-Stemmed Bridge Unit

## APPENDIX B

## Product Dimensional Tolerances

### B-14 Multi-Stemmed Bridge Unit

a = Length .....	$\pm 3/4$ in. [ $\pm 19$ mm]	$m_1$ = Location of Bearing Assembly ..	$\pm 1/2$ in. [ $\pm 13$ mm]
b = Width (overall) .....	$\pm 1/4$ in. [ $\pm 6$ mm]	$m_2$ = Tipping and Flushness of Bearing Assembly .....	$\pm 1/8$ in. [ $\pm 3$ mm]
$b_1$ = Stem Width .....	$\pm 1/4$ in. [ $\pm 6$ mm]	$m_3$ = Differential Elevation of Bearing Surface Between Stems .....	$\pm 1/16$ in. [ $\pm 2$ mm]
$b_2$ = Distance Between Stems .....	$\pm 1/8$ in. [ $\pm 3$ mm]	$n_1$ = Location of Blockout .....	$\pm 1$ in. [ $\pm 25$ mm]
$b_3$ = Stem to Edge of Top Flange .....	$\pm 1/4$ in. [ $\pm 6$ mm]	$n_2$ = Size of Blockouts .....	$\pm 1$ in. [ $\pm 25$ mm]
$b_4$ = Shear Key Width .....	$\pm 1/4$ in. [ $\pm 6$ mm]	o = Location of Sleeves Cast in Stems, in Both Horizontal and Vertical Plane .....	$\pm 1/2$ in. [ $\pm 13$ mm]
c = Depth (overall) .....	$\pm 1/4$ in. [ $\pm 6$ mm]	p = Location of Inserts for Structural Connections .....	$\pm 1/2$ in. [ $\pm 13$ mm]
$c_1$ = Flange Thickness .....	+ $1/4$ in., - $1/8$ in. .....[+ 6 mm, - 3 mm]	$q_1$ = Location of Handling Device Parallel to Length of Member .....	$\pm 6$ in. [ $\pm 150$ mm]
$c_2$ = Shear Key Depth .....	$\pm 1/4$ in. [ $\pm 6$ mm]	$q_2$ = Location of Handling Device Transverse to Length of Member .....	$\pm 1$ in. [ $\pm 25$ mm]
d = Variation From Specified Plan End Squareness or Skew .....	$\pm 3/4$ in. [ $\pm 19$ mm]	s = Longitudinal Spacing of Stirrups ..	$\pm 1$ in. [ $\pm 25$ mm]
e = Variation From Specified Elevation End Squareness or Skew .....	$\pm 3/4$ in. [ $\pm 19$ mm]		
f = Sweep, for Member Length:			
up to 40 ft. [12 m] .....	$\pm 1/4$ in. [ $\pm 6$ mm]		
40 to 60 ft. [12 to 18 m] .....	$\pm 3/8$ in. [ $\pm 10$ mm]		
greater than 60 ft. [18 m] .....	$\pm 1/2$ in. [ $\pm 13$ mm]		
g = Camber Variation from Design Camber .....	$\pm 1/4$ in. per 10 ft., $\pm 3/4$ in. maximum .....[ $\pm 6$ mm per 3 m, $\pm 19$ mm maximum]		
$g_1$ = Differential Camber Between Adjacent Units of the Same Design .....	$1/4$ in. per 10 ft., $3/4$ in. maximum .....[6 mm per 3 m, 19 mm maximum]		
k = Location of Strand			
individual .....	$\pm 1/4$ in. [ $\pm 6$ mm]		
bundled .....	$\pm 1/2$ in. [ $\pm 13$ mm]		
$k_1$ = Location of Harp Points for Harped Strands from Design Location .....	$\pm 6$ in. [ $\pm 150$ mm]		
$l_1$ = Location of Embedment .....	$\pm 1$ in. [ $\pm 25$ mm]		
$l_2$ = Tipping and Flushness of Embedment .....	$\pm 1/4$ in. [ $\pm 6$ mm]		

See pages B.1 through B.4 for additional information and explanation of tolerance requirements for camber, harp point location, and local smoothness.

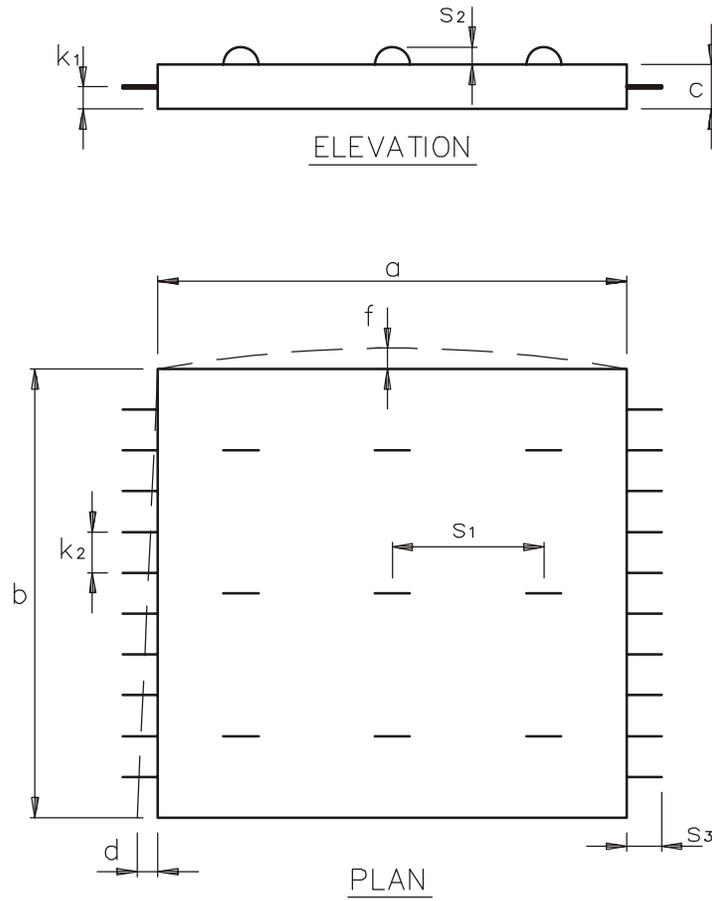


Figure B-15 Bridge Deck Unit

**B-15 Bridge Deck Unit**

- a = Length .....  $\pm 1/4$  in. [ $\pm 6$  mm]
- b = Width .....  $\pm 1/4$  in. [ $\pm 6$  mm]
- c = Depth .....  $+ 1/4$  in.,  $- 1/8$  in. [ $+ 6$  mm,  $- 3$  mm]
- d = Variation From Specified Plan End Squareness or Skew .....  $\pm 1/4$  in. [ $\pm 6$  mm]
- f = Sweep .....  $\pm 1/8$  in. [ $\pm 3$  mm]
- k<sub>1</sub> = Location of Strand Perpendicular to Plane of Panel .....  $\pm 1/8$  in. [ $\pm 3$  mm]
- k<sub>2</sub> = Location of Strand Parallel to Plane of Panel .....  $\pm 1/4$  in. [ $\pm 6$  mm]
- s<sub>1</sub> = Longitudinal Spacing of Stirrups .....  $\pm 1$  in. [ $\pm 25$  mm]
- s<sub>2</sub> = Stirrup Projection from Surface .....  $\pm 1/2$  in. [ $\pm 13$  mm]
- s<sub>3</sub> = Strand Projection from End .....  $\pm 1/2$  in. [ $\pm 13$  mm]

See page B.4 for additional information and explanation of tolerance requirement for sweep.

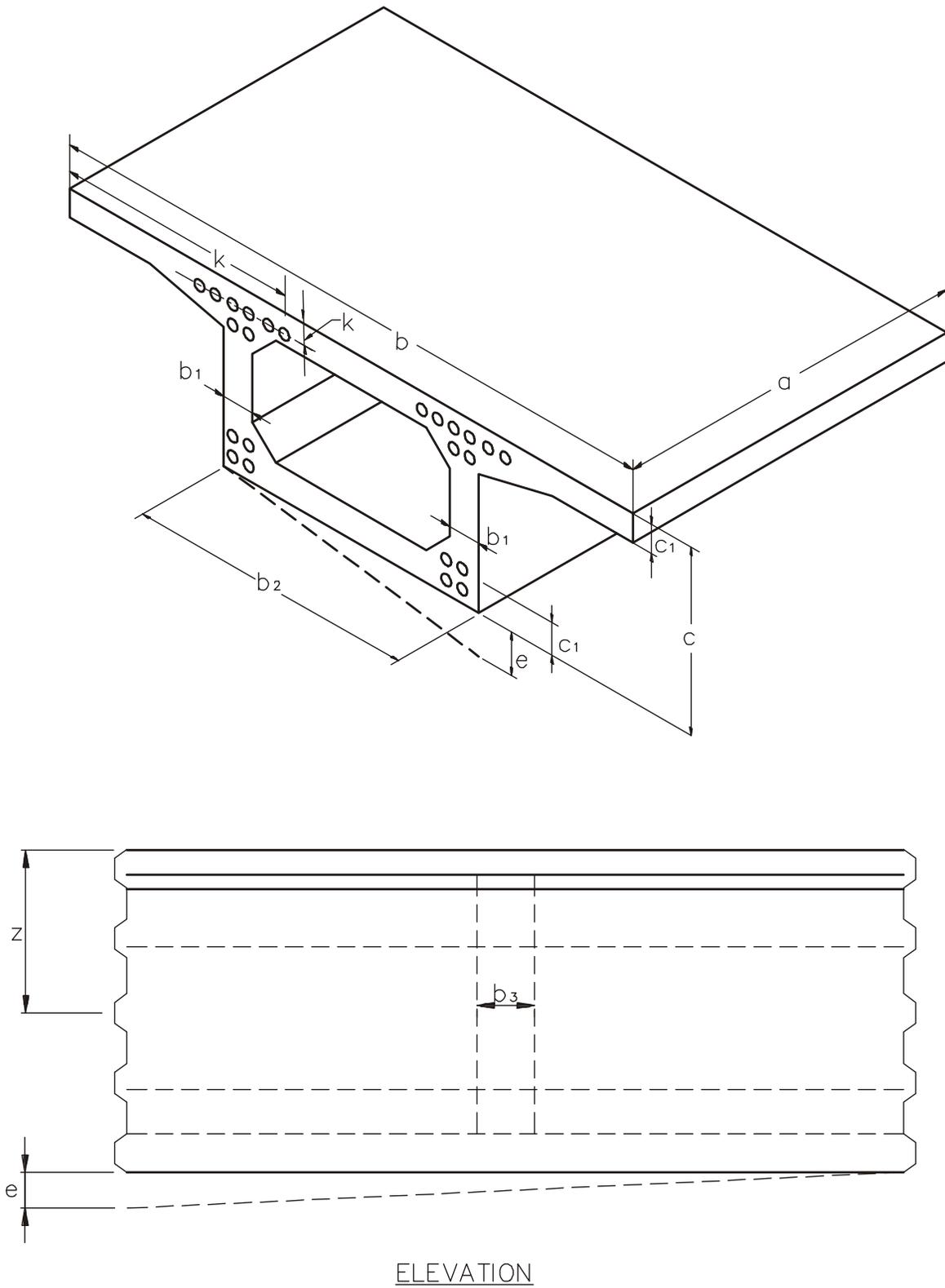


Figure B-16 Segmental Box Girder

**B-16 Segmental Box Girder**

- a = Length .....  $\pm 1/8$  in/ft length,  $\pm 1$  in. maximum  
..... [ $\pm 10$  mm/m length,  $\pm 25$  mm maximum]
  
- b = Width (overall)  
.....  $\pm 1/16$  in/ft width,  $\pm 3/4$  in. maximum  
..... [ $\pm 5$  mm/m length,  $\pm 19$  mm maximum]
  
- b<sub>1</sub> = Web Width .....  $\pm 3/8$  in [ $\pm 10$  mm]
  
- b<sub>2</sub> = Bottom Flange Width  
.....  $\pm 1/16$  in/ft width,  $\pm 1/2$  in. maximum  
..... [ $\pm 5$  mm/m length,  $\pm 13$  mm maximum]
  
- b<sub>3</sub> = Diaphragm Thickness .....  $\pm 1/2$  in [ $\pm 13$  mm]
  
- c = Depth (overall) .....  $\pm 1/4$  in. [ $\pm 6$  mm]
  
- c<sub>1</sub> = Depth of Top and Bottom Slab  
.....  $\pm 3/8$  in. [ $\pm 10$  mm]
  
- e = Grade of Form Edge and Soffit (Vertical Curve and  
Superelevation)  
.....  $\pm 1/8$  in. in 10 ft. [ $\pm 3$  mm in 3 m]
  
- k = Location of Post-Tensioning Duct  
.....  $\pm 1/8$  in. [ $\pm 3$  mm]
  
- z = Location of Shear Key .....  $\pm 1/4$  in. [ $\pm 6$  mm]

Note: The above tolerances should be compared to the specific requirements of the project tolerance control plan and adjusted as necessary.

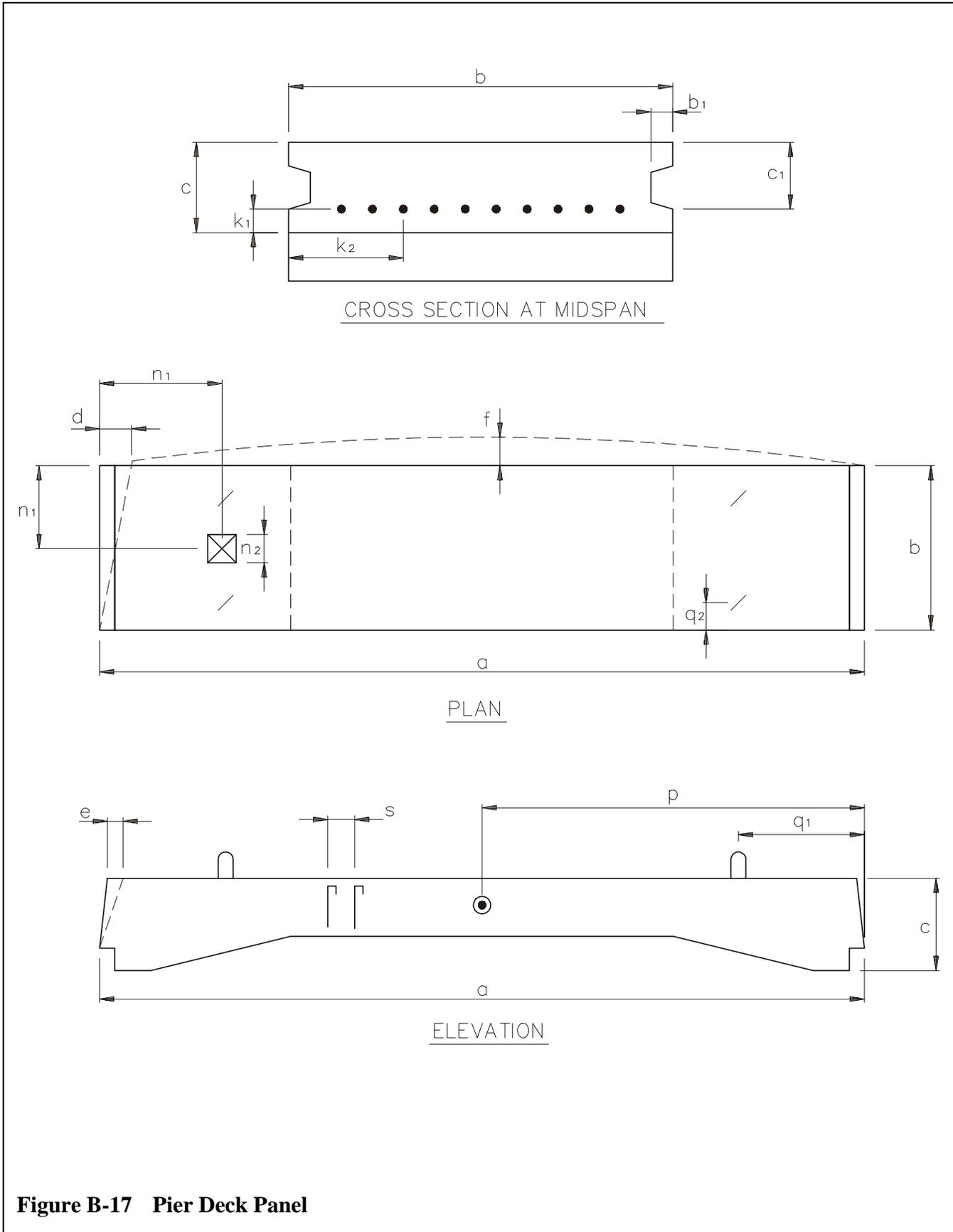


Figure B-17 Pier Deck Panel

**B-17 Pier Deck Panel**

- a = Length .....  $\pm 1/2$  in. [ $\pm 13$  mm]
- b = Width .....  $\pm 1/4$  in. [ $\pm 6$  mm]
- b<sub>1</sub> = Shear Key Width .....  $\pm 1/4$  in [ $\pm 6$  mm]
- c = Depth .....  $\pm 1/4$  in. [ $\pm 6$  mm]
- c<sub>1</sub> = Shear Key Depth .....  $\pm 1/4$  in. [ $\pm 6$  mm]
- d = Variation From Specified Plan End Squareness or Skew .....  $\pm 1/2$  in. [ $\pm 13$  mm]
- e = Variation From Specified Elevation End Squareness or Skew .....  $\pm 1/2$  in. [ $\pm 13$  mm]
- f = Sweep .....  $\pm 1/8$  in. per 10 ft. [ $\pm 3$  mm per 3 m]
- g = Differential Camber Between Adjacent Units of the Same Design .....  $1/4$  in. per 10 ft. [6 mm per 3 m]
- k<sub>1</sub> = Location of Strand Perpendicular to Plane of Panel .....  $\pm 1/4$  in. [ $\pm 6$  mm]
- k<sub>2</sub> = Location of Strand Parallel to Plane of Panel .....  $\pm 1$  in. [ $\pm 25$  mm]
- n<sub>1</sub> = Location of Blockout .....  $\pm 1$  in. [ $\pm 25$  mm]
- n<sub>2</sub> = Size of Blockouts .....  $\pm 1$  in. [ $\pm 25$  mm]
- p = Location of Inserts .....  $\pm 1$  in. [ $\pm 25$  mm]
- q<sub>1</sub> = Location of Handling Device Parallel to Length of Member .....  $\pm 6$  in. [ $\pm 150$  mm]
- q<sub>2</sub> = Location of Handling Device Transverse to Length of Member .....  $\pm 1$  in. [ $\pm 25$  mm]
- s = Longitudinal Spacing of Stirrups .....  $\pm 1$  in. [ $\pm 25$  mm]

See pages B.3 and B.4 for additional information and explanation of tolerance requirements for camber and sweep.

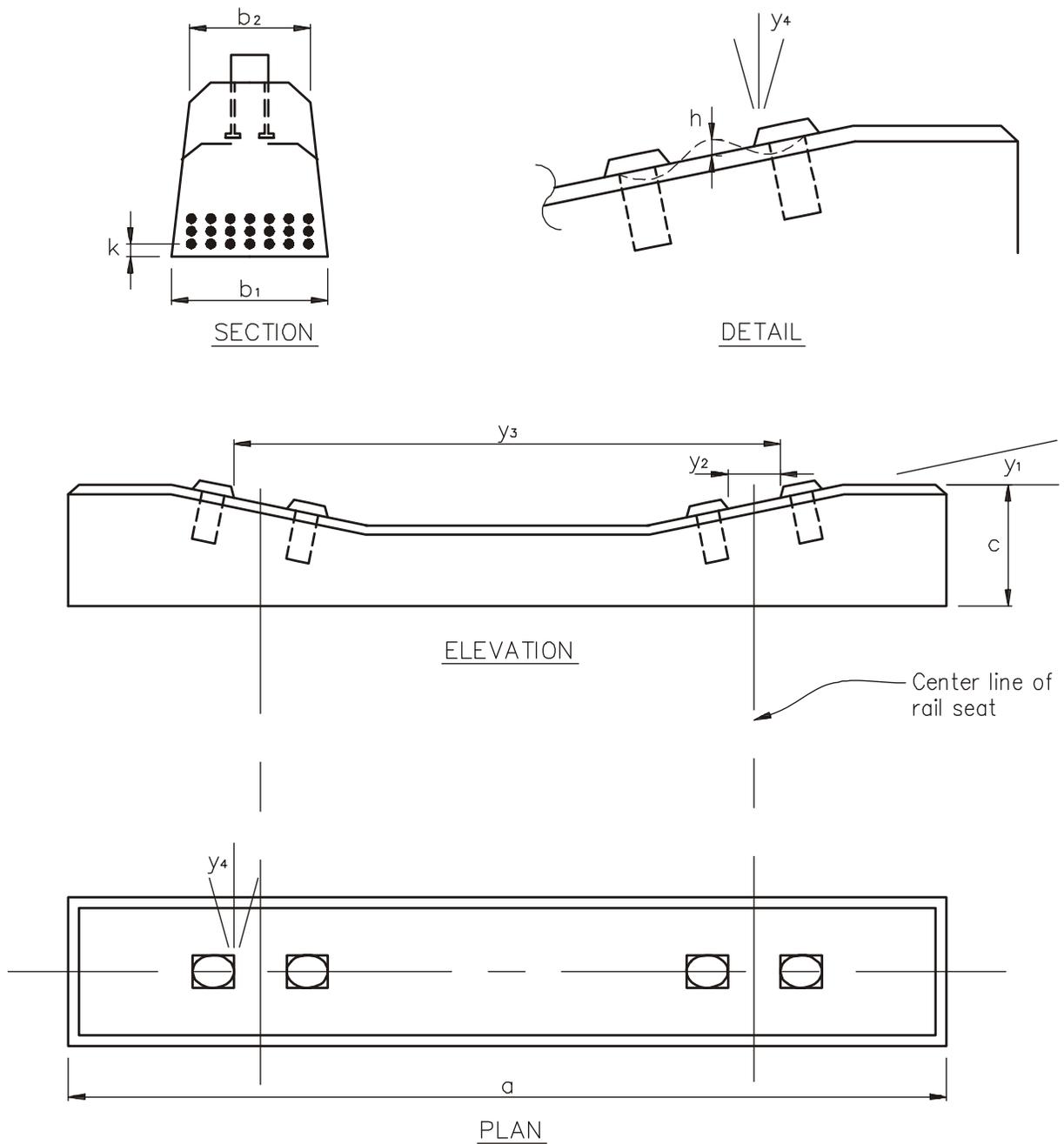


Figure B-18 Railroad Tie

**B-18 Railroad Tie †**

- a = Length .....  $\pm 1/8$  in. up to 108 in. length  
..... [ $\pm 3$  mm up to 2700 mm length]
  
- b<sub>1</sub> = Width at Bottom .....  $\pm 1/8$  in. [ $\pm 3$  mm]
  
- b<sub>2</sub> = Width at Top .....  $\pm 1/8$  in. [ $\pm 3$  mm]
  
- c = Depth .....  $\pm 3/16$  in. up to 10 in. depth  
..... [ $\pm 5$  mm up to 250 mm depth]
  
- h = Local Smoothness .....  
.....  $1/32$  in. over 6 sq. in. area of rail seat  
..... [1 mm over 3870 mm<sup>2</sup> area of rail seat]
  
- k = Location of Strand or Wire .....  $\pm 1/8$  in. [ $\pm 3$  mm]
  
- y<sub>1</sub> = Rail Seat Slope .....  $\pm 5$  degrees
  
- y<sub>2</sub> = Spacing Between Adjacent Inserts for Rail  
Attachment .....  $+ 1/16$  in., - 0 in. up to 7 in. spacing  
..... [+ 2 mm, - 0 mm up to 180 mm spacing]
  
- y<sub>3</sub> = Spacing Between Inserts for Setting Track Gage  
.....  $\pm 0.08$  in. up to 70 in. spacing  
..... [ $\pm 2$  mm up to 1800 mm spacing]
  
- y<sub>4</sub> = Shoulder Tilt, Vertical or Horizontal .....  $\pm 2$  degrees

† Current tolerances as published by American Railroad Engineers Association (AREA) Committee No. 8 should be reviewed prior to production.

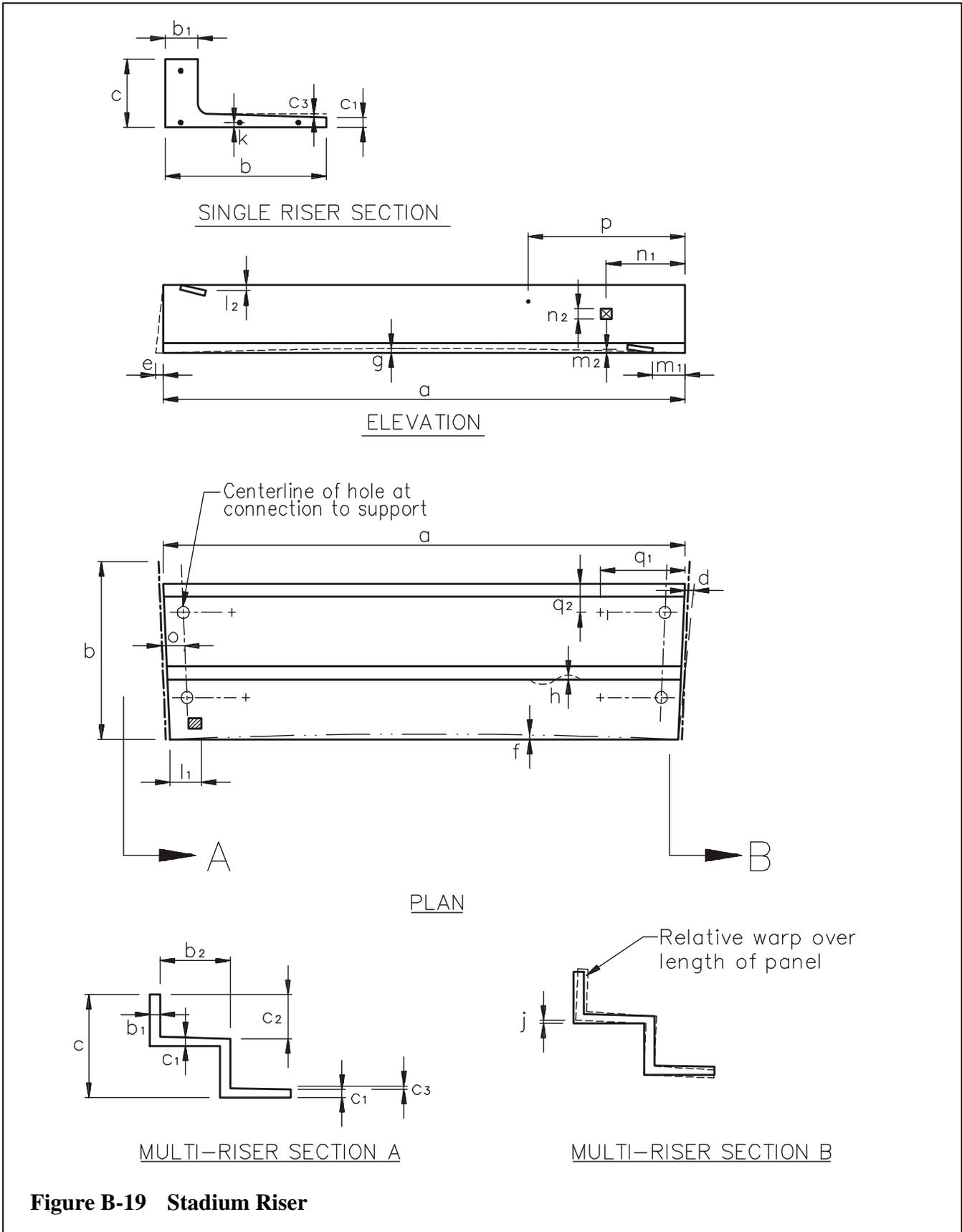


Figure B-19 Stadium Riser

## APPENDIX B

## Product Dimensional Tolerances

### B-19 Stadium Riser

a = Length .....	$\pm 1/2$ in. [ $\pm 13$ mm]	$m_1$ = Location of Bearing Assembly ..	$\pm 1/2$ in. [ $\pm 13$ mm]
b = Width (overall) .....	$\pm 1/4$ in. [ $\pm 6$ mm]	$m_2$ = Tipping and Flushness of Bearing Assembly .....	$\pm 1/8$ in. [ $\pm 3$ mm]
$b_1$ = Stem Width .....	$\pm 1/8$ in. [ $\pm 3$ mm]	$n_1$ = Location of Blockout .....	$\pm 1$ in. [ $\pm 25$ mm]
$b_2$ = Individual Tread Width (not cumulative) .....	$\pm 1/8$ in. [ $\pm 3$ mm]	$n_2$ = Size of Blockouts .....	$\pm 1$ in. [ $\pm 25$ mm]
c = Depth (overall) .....	$\pm 1/4$ in. [ $\pm 6$ mm]	o = Location of Sleeves at Connection to Support .....	$\pm 1/2$ in. [ $\pm 13$ mm]
$c_1$ = Flange Thickness .....	+ $1/4$ in., - $1/8$ in. [+ 6 mm, - 3 mm]	p = Location of Inserts .....	$\pm 1/2$ in. [ $\pm 13$ mm]
$c_2$ = Individual Riser Depth (not cumulative) .....	$\pm 1/8$ in. [ $\pm 3$ mm]	$q_1$ = Location of Handling Device Parallel to Length of Member.....	$\pm 6$ in. [ $\pm 150$ mm]
$c_3$ = Riser Variation from Specified Plane .....	+ $1/8$ in., - 0 in. [+ 3 mm, - 0 mm]	$q_2$ = Location of Handling Device Transverse to Length of Member.....	$\pm 1$ in. [ $\pm 25$ mm]
d = Variation From Specified Plan End Squareness or Skew .....	$\pm 1/8$ in. per 12 in. width, $1/4$ in. maximum [ $\pm 3$ mm per 300 mm width, 6 mm maximum]		
e = Variation From Specified Elevation End Squareness or Skew .....	$\pm 1/4$ in. per 12 in. height, $\pm 1/2$ in. maximum [ $\pm 6$ mm per 300 mm height, $\pm 13$ mm maximum]		
f = Sweep .....	$\pm 1/4$ in. per 40 ft. length, $\pm 3/8$ in. maximum [ $\pm 6$ mm per 12 m length, $\pm 10$ mm maximum]		
g = Camber Variation from Design Camber .....	$\pm 1/4$ in. per 10 ft., $\pm 1/2$ in. maximum [ $\pm 6$ mm per 3 m, $\pm 13$ mm maximum]		
$g_1$ = Differential Camber Between Adjacent Units of the Same Design .....	$1/4$ in. per 10 ft., $1/2$ in. maximum [6 mm per 3 m, 13 mm maximum]		
h = Local Smoothness of Any Surface .....	$1/4$ in. in 10 ft. [6 mm in 3 m]		
j = Warp .....	$\pm 1/4$ in. [ $\pm 6$ mm]		
k = Location of Strand .....	$\pm 1/4$ in. [ $\pm 6$ mm]		
$l_1$ = Location of Embedment .....	$\pm 1$ in. [ $\pm 25$ mm]		
$l_2$ = Tipping and Flushness of Embedment .....	$\pm 1/4$ in. [ $\pm 6$ mm]		

See pages B.1 through B.4 for additional information and explanation of tolerance requirement for sweep, camber, warp, and local smoothness.

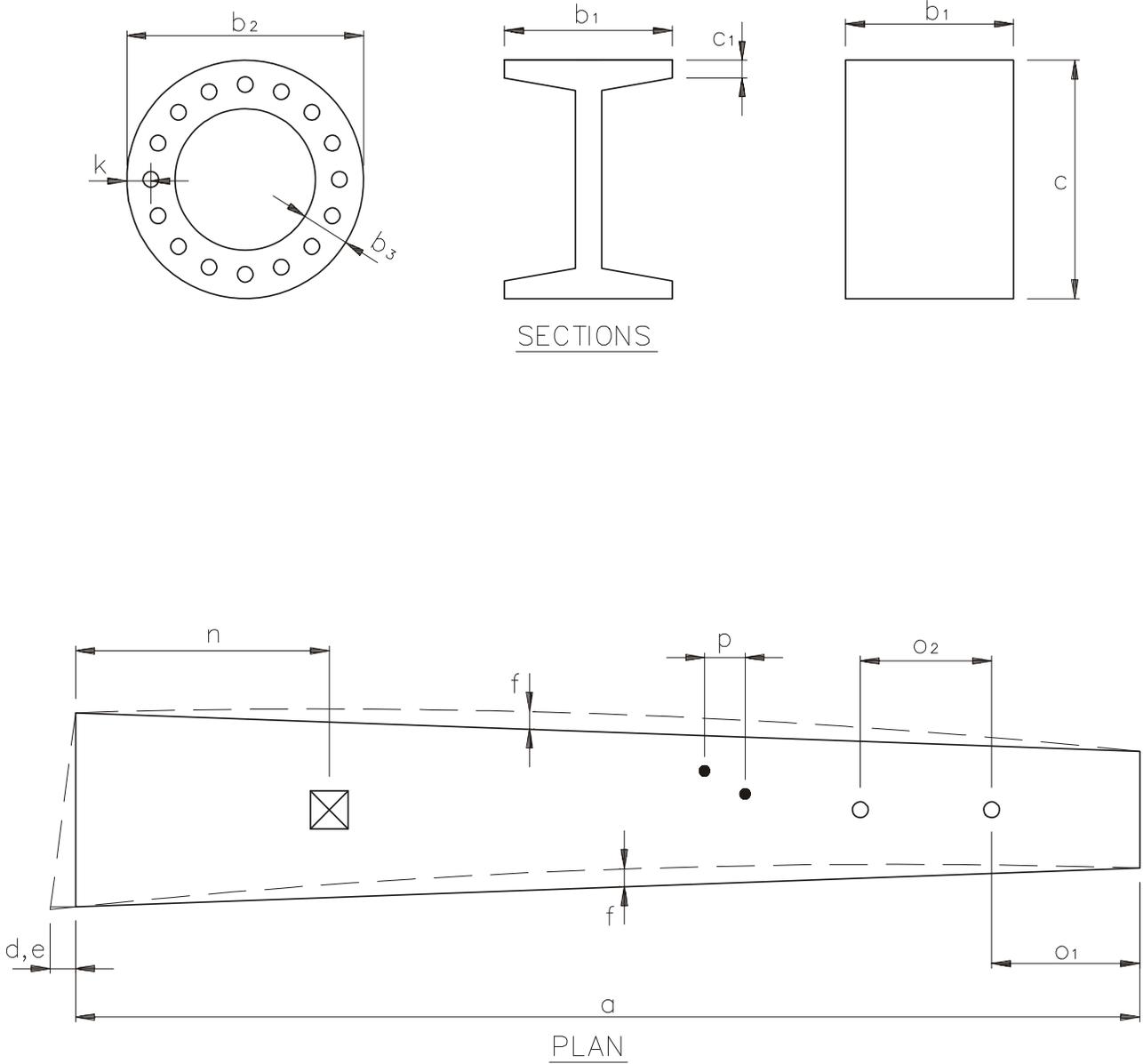


Figure B-20 Pole

## APPENDIX B

## Product Dimensional Tolerances

### B-20 Pole

- a = Length .....  
.....  $\pm 1/8$  in. per 10 ft. or  $\pm 2$  in., whichever is greater  
.. [ $\pm 3$  mm per 3 m or  $\pm 50$  mm, whichever is greater]
- b<sub>1</sub> = Width, Static Cast Poles  
less than 24 in. [600 mm] width  
.....  $\pm 3/8$  in. [ $\pm 10$  mm]  
24 to 36 in. [600 to 900 mm] width  
.....  $\pm 1/2$  in. [ $\pm 13$  mm]  
greater than 36 in. [900 mm] width .....  
.....  $\pm 5/8$  in. [ $\pm 16$  mm]
- b<sub>2</sub> = Diameter, Spun Poles .....  $\pm 1/4$  in. [ $\pm 6$  mm]
- b<sub>3</sub> = Wall Thickness .....  $\pm 1/4$  in. [ $\pm 6$  mm]  
or + 20, - 10 percent of nominal thickness, whichever  
is greater
- c = Depth, Static Cast Poles  
less than 24 in. [600 mm] width  
.....  $\pm 3/8$  in. [ $\pm 10$  mm]  
24 to 36 in. [600 to 900 mm] width  
.....  $\pm 1/2$  in. [ $\pm 13$  mm]  
greater than 36 in. [900 mm] width .....  
.....  $\pm 5/8$  in. [ $\pm 16$  mm]
- c<sub>1</sub> = Flange Thickness .....  $\pm 1/4$  in. [ $\pm 6$  mm ]
- d = Variation From Specified Plan End Squareness or  
Skew  
top .....  $\pm 1/4$  in. [ $\pm 6$  mm ]  
bottom .....  $\pm 1$  in. [ $\pm 25$  mm ]  
.....
- e = Variation From Specified Elevation End Squareness  
or Skew  
top .....  $\pm 1/4$  in. [ $\pm 6$  mm ]  
bottom .....  $\pm 1$  in. [ $\pm 25$  mm ]  
.....
- f = Sweep .....  
 $\pm 1/4$  in. per 10 ft. or  $\pm 1/2$  in., whichever is greater  
[ $\pm 6$  mm per 3 m or  $\pm 13$  mm, whichever is greater]
- k = Location of Strand .....  $\pm 1/4$  in. [ $\pm 6$  mm]
- n = Location of Blockout .....  $\pm 1$  in. [ $\pm 25$  mm]

- o<sub>1</sub> = Location of Sleeve .....  $\pm 1$  in. [ $\pm 25$  mm]
- o<sub>2</sub> = Location of Sleeve for Matching Hardware Pattern  
.....  $\pm 1/8$  in. [ $\pm 3$  mm]
- p = Location of Insert for Matching Hardware Pattern  
.....  $\pm 1/8$  in. [ $\pm 3$  mm]
- x = Weight .....  $\pm 8$  percent of nominal weight

See page B.4 for additional information and explanation of  
tolerance requirement for sweep.

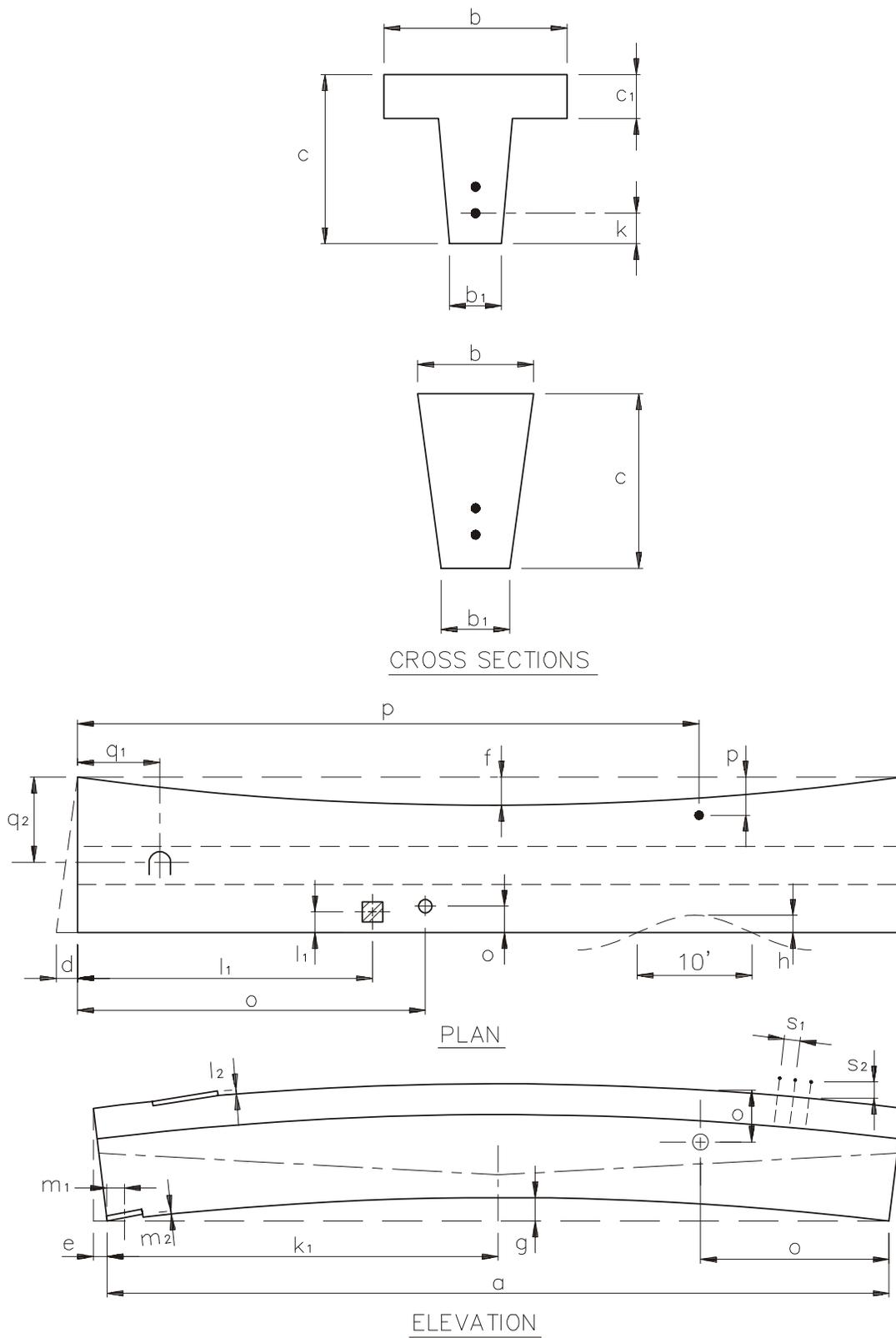


Figure B-21 Tee Joist or Keystone Joist

## APPENDIX B

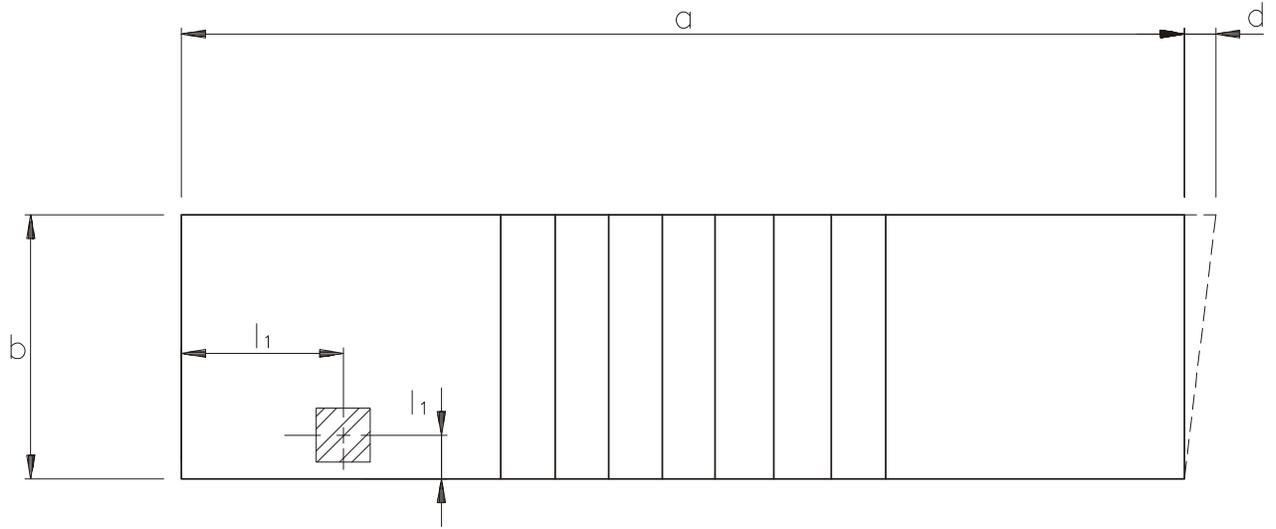
## Product Dimensional Tolerances

### B-21 Tee Joist or Keystone Joist

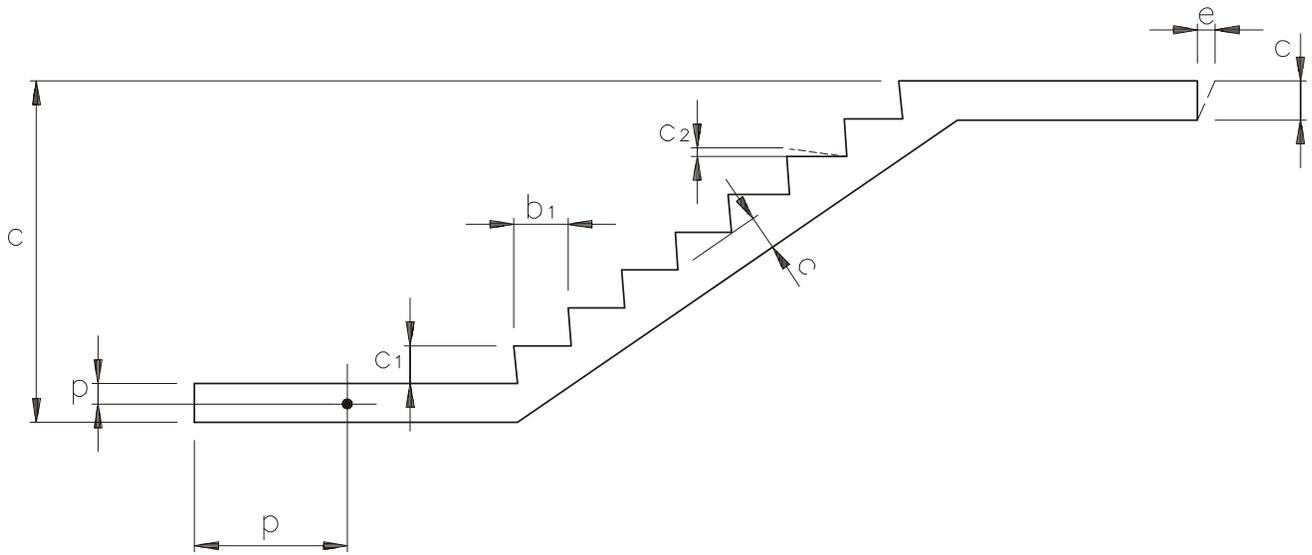
- a = Length .....  $\pm 1$  in. [ $\pm 25$  mm]
- b = Width (overall) .....  $\pm 1/4$  in. [ $\pm 6$  mm]
- b<sub>1</sub> = Stem Width .....  $\pm 1/8$  in. [ $\pm 3$  mm]
- c = Depth (overall) .....  $\pm 1/4$  in. [ $\pm 6$  mm]
- c<sub>1</sub> = Flange Thickness .....  $+ 1/4$  in.,  $- 1/8$  in.  
..... [ $+ 6$  mm,  $- 3$  mm]
- d = Variation From Specified Plan End Squareness or  
Skew ..  $\pm 1/4$  in. per 12 in. width,  $\pm 1/2$  in. maximum  
..... [ $\pm 6$  mm per 300 mm width,  $\pm 13$  mm maximum]
- e = Variation From Specified Elevation End Squareness  
or Skew  
.....  $\pm 1/4$  in. per 12 in. height,  $\pm 1/2$  in. maximum  
..... [ $\pm 6$  mm per 300 mm height,  $\pm 13$  mm maximum]
- f = Sweep, for Member Length:
- up to 40 ft. [12 m] .....  $\pm 3/8$  in. [ $\pm 10$  mm]  
    40 to 60 ft. [12 to 18 m] .....  $\pm 5/8$  in. [ $\pm 16$  mm]  
    greater than 60 ft. [18 m] .....  $\pm 3/4$  in. [ $\pm 19$  mm]
- g = Camber Variation from Design Camber .....  
.....  $\pm 1/4$  in. per 10 ft.,  $\pm 3/4$  in. maximum  
..... [ $\pm 6$  mm per 3 m,  $\pm 19$  mm maximum]
- h = Local Smoothness of Any Surface .....  
.....  $1/4$  in. in 10 ft. [6 mm in 3 m]
- k = Location of Strand
- individual .....  $\pm 1/4$  in. [ $\pm 6$  mm]  
    bundled .....  $\pm 1/2$  in. [ $\pm 13$  mm]
- k<sub>1</sub> = Location of Harp Points for Harped Strands from  
Design Location .....  $\pm 20$  in [ $\pm 510$  mm]
- l<sub>1</sub> = Location of Embedment .....  $\pm 1$  in. [ $\pm 25$  mm]
- l<sub>2</sub> = Tipping and Flushness of Embedment .....  
.....  $\pm 1/4$  in. [ $\pm 6$  mm]
- m<sub>1</sub> = Location of Bearing Assembly ...  $\pm 1/2$  in. [ $\pm 13$  mm]
- m<sub>2</sub> = Tipping and Flushness of Bearing Assembly .....  
.....  $\pm 1/8$  in. [ $\pm 3$  mm]
- o = Location of Sleeves Cast in Stem, in Both Horizontal  
and Vertical Plane .....  $\pm 1$  in. [ $\pm 25$  mm]

- p = Location of Insert for Structural Connections .....  
.....  $\pm 1/2$  in. [ $\pm 13$  mm]
- q<sub>1</sub> = Location of Handling Device Parallel to Length of  
Member .....  $\pm 6$  in. [ $\pm 150$  mm]
- q<sub>2</sub> = Location of Handling Device Transverse to Length of  
Member .....  $\pm 1$  in. [ $\pm 25$  mm]
- s<sub>1</sub> = Longitudinal Spacing of Stirrups ...  $\pm 2$  in. [ $\pm 50$  mm]
- s<sub>2</sub> = Stirrup Projection from Beam Surface  
.....  $+ 1/4$  in.,  $- 1/2$  in. [ $+ 6$  mm,  $- 13$  mm]

See pages B.1 through B.4 for additional information and explanation of tolerance requirements for sweep, camber, harp point location, and local smoothness.



PLAN



ELEVATION

Figure B-22 Stair Unit

**B-22 Stair Unit**

a	= Length .....	$\pm 1/2$ in. [ $\pm 13$ mm]
b	= Width (overall) .....	$\pm 3/8$ in. [ $\pm 10$ mm]
b <sub>1</sub>	= Individual Tread Width (not cumulative) .....	$\pm 1/4$ in. [ $\pm 6$ mm]
c	= Depth (overall) .....	$\pm 1/4$ in. [ $\pm 6$ mm]
c <sub>1</sub>	= Individual Riser Depth (not cumulative) .....	$\pm 3/16$ in. [ $\pm 5$ mm]
c <sub>2</sub>	= Riser Variation from Specified Plane .....	+ 1/8 in., - 0 in. [+ 3 mm, - 0 mm]
c <sub>3</sub>	= Differential Height Between Adjacent Risers <sup>†</sup> .....	$\pm 1/4$ in. [ $\pm 6$ mm]
d	= Variation From Specified Plan End Squareness or Skew .....	$\pm 1/8$ in. per 12 in. width, 1/2 in. maximum $\pm 3$ mm per 300 mm width, 13 mm maximum
e	= Variation From Specified Elevation End Squareness or Skew .....	$\pm 1/4$ in. [ $\pm 6$ mm]
j	= Warp .....	$\pm 1/4$ in. [ $\pm 6$ mm]
l <sub>1</sub>	= Location of Embedment .....	$\pm 1$ in. [ $\pm 25$ mm]
l <sub>2</sub>	= Tipping and Flushness of Embedment .....	$\pm 1/8$ in. [ $\pm 3$ mm]
p	= Location of Inserts for Structural Connections .....	$\pm 3/8$ in. [ $\pm 10$ mm]

<sup>†</sup> Local building codes may restrict the maximum height differential between risers. The building code shall govern.

See pages B.1 through B.3 for additional information and explanation of tolerance requirement for warp.

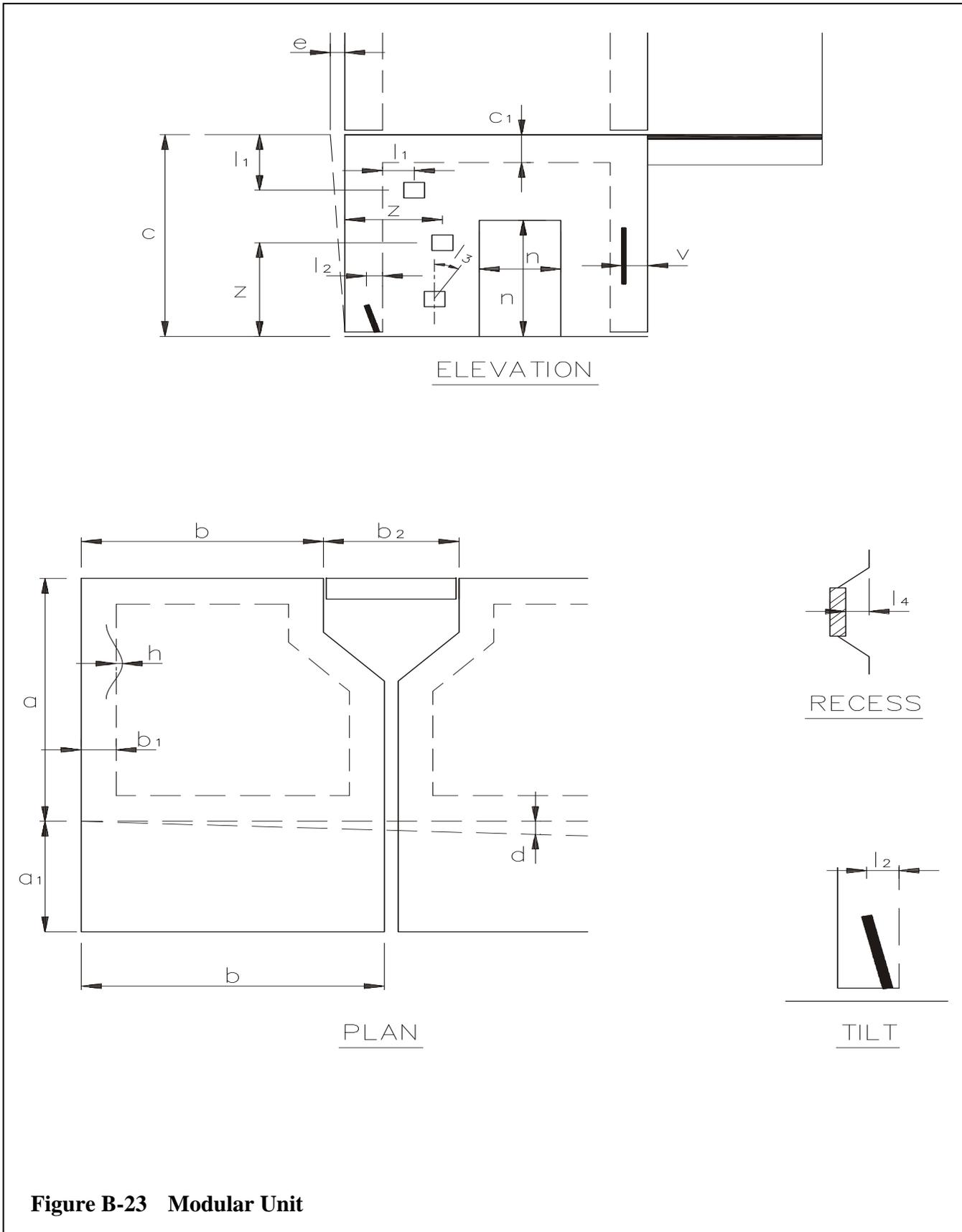


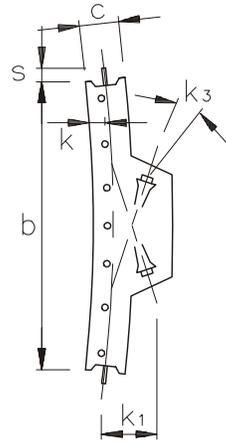
Figure B-23 Modular Unit

**B-23 Modular Unit**

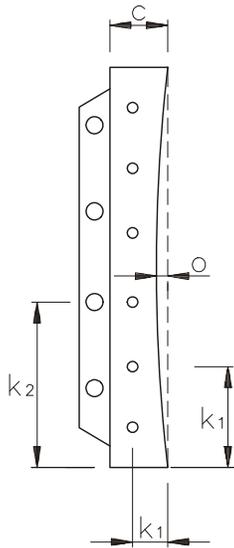
See pages B.3 and B.4 for additional information and explanation of tolerance requirement for local smoothness.

- a = Length .....  $\pm 3/8$  in. [ $\pm 10$  mm]
- a<sub>1</sub> = Length of Balcony Extension .....  $\pm 1/4$  in. [ $\pm 6$  mm]
- b = Width (overall)
  - single unit .....  $\pm 1/4$  in. [ $\pm 6$  mm]
  - multiple unit .....  $\pm 1/2$  in. [ $\pm 13$  mm]
- b<sub>1</sub> = Wall Thickness ....  $+ 1/4$  in., - 0 in. [ $+ 6$  mm, - 0 mm]
- b<sub>2</sub> = Width of Closure Panel between Units  
.....  $+ 0$  in., -  $1/2$  in. [ $+ 0$  mm, - 13 mm]
- c = Depth (overall) .....  $\pm 1/4$  in. [ $\pm 6$  mm]
- c<sub>1</sub> = Slab Thickness .....  $\pm 1/4$  in. [ $\pm 6$  mm]
- d = Variation From Specified Plan End Squareness or Skew .....  $\pm 1/4$  in. [ $\pm 6$  mm]
- e = Variation From Specified Elevation End Squareness or Skew .....  $\pm 1/8$  in. [ $\pm 3$  mm]
- h = Local Smoothness of Any Surface .....  
.....  $1/4$  in. in 10 ft. [6 mm in 3 m]
- l<sub>1</sub> = Location of Embedment .....  $\pm 1/2$  in. [ $\pm 13$  mm]
- l<sub>2</sub> = Tipping and Flushness of Embedment .....  
.....  $\pm 1/8$  in. [ $\pm 3$  mm]
- l<sub>3</sub> = Angular Rotation of Visible Embedment or Blockout  
..... 2 degrees  
 $1/4$  in. [6 mm] maximum measured at perimeter of  
embedment or blockout
- l<sub>4</sub> = Depth of Recess to Embedment .....  
.....  $+ 1/4$  in., -  $1/8$  in. [ $+ 6$  mm, -3mm]
- n = Size of Blockout for Door or Window .....  
.....  $\pm 1/8$  in. [ $\pm 3$  mm]
- v = Cover over Reinforcement .....  $\pm 1/4$  in. [ $\pm 6$  mm]
- z = Location of Electrical Boxes .....  $\pm 1$  in. [ $\pm 25$  mm]

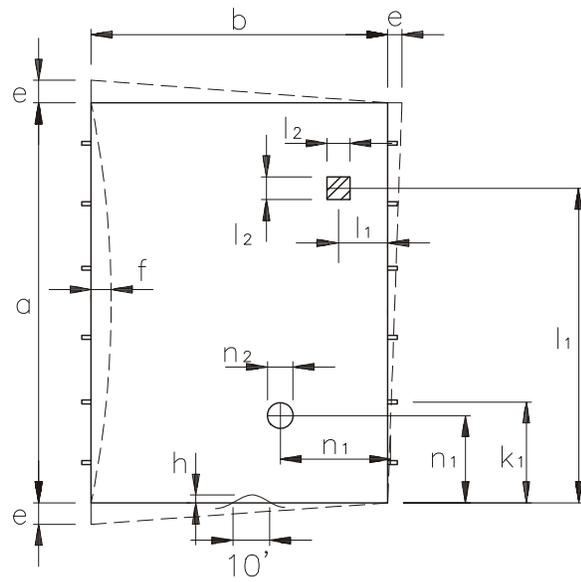
Tolerances for project specific items, such as security hardware, mechanical/electrical/plumbing embedments, doors, and windows, should be included in the contract documents.



PLAN



ELEVATION



ELEVATION

Figure B-24 Storage Tank Panel

**B-24 Storage Tank Panel**

- a = Length .....  $\pm 1/4$  in. [ $\pm 6$  mm]
- b = Width (overall) .....  $\pm 1/4$  in. [ $\pm 6$  mm]
- c = Depth (overall) .....  
 .....  $+ 1/4$  in.,  $- 1/8$  in. [ $+ 6$  mm,  $- 0$  mm]
- e = Variation From Specified Elevation End Squareness  
 or Skew  
 .....  $\pm 1/8$  in. per 72 in. length,  $\pm 1/4$  in. maximum  
 ..... [ $\pm 3$  mm per 1800 mm,  $\pm 6$  mm maximum]
- f = Sweep .....  $\pm 3/8$  in. [ $\pm 10$  mm]
- h = Local Smoothness  
  
 of horizontal surface ....  $1/8$  in. in 10 ft. [3 mm in 3 m]  
 of vertical surface .....  $1/4$  in. in 10 ft. [6 mm in 3 m]
- i = Bow ..... Length/360,  $3/4$  in. [19 mm] maximum
- $i_1$  = Differential Bow Between Adjacent Panels of the  
 Same Design .....  $3/8$  in. [10 mm]
- k = Location of Strand .....  $\pm 1/4$  in. [ $\pm 6$  mm]
- $k_1$  = Location of Post-Tensioning Duct  
 .....  $\pm 1/8$  in. [ $\pm 3$  mm]
- $k_2$  = Location of Post-Tensioning Anchor  
 .....  $\pm 1/4$  in. [ $\pm 6$  mm]
- $k_3$  = Angular Rotation of Post-Tensioning Anchor from  
 Specified Alignment .....  $\pm 5$  degrees
- $l_1$  = Location of Embedment .....  $\pm 3/4$  in. [ $\pm 19$  mm]
- $l_2$  = Size of Embedment .....  $\pm 1/8$  in. [ $\pm 3$  mm]
- $n_1$  = Location of Blockout .....  $\pm 3/4$  in. [ $\pm 19$  mm]
- $n_2$  = Size of Blockouts .....  $\pm 1/4$  in. [ $\pm 6$  mm]
- s = Projection of Post-Tensioning Duct .....  
 .....  $\pm 1/2$  in. [ $\pm 13$  mm]

See pages B.1 through B.4 for additional information and explanation of tolerance requirements for bow and local smoothness.

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# APPENDIX C

## Finishes

### Introduction

Finish requirements should be agreed upon with the client at the beginning of the project. Refer to Article 2.8 for general finish requirements.

The following finish descriptions may be used to define specification requirements. The minimum finish grade consistent with a product's application and the intended use of the structure should be specified. Precasters should be consulted regarding the finishes appropriate for various products and cost effectiveness.

### Formed Finishes

**Commercial Grade** – This is essentially an “as cast” finish. Concrete may be produced in forms that impart a texture to the concrete, (e.g., plywood lumber or steel forms with offset joints, dents or holes). The surface may contain air holes (bug holes) and water marks, and there may be some minor chips and spalls. There may be some scaling and/or scouring. There may be patches and streaks of color variation within the surface, and the overall color tone may vary between pieces.

Large fins from joint bleeding should be removed, but small fins may remain. Only “honeycombed” and/or badly spalled areas should be repaired or finished. All faces should have true, well-defined surfaces. The maximum allowable form joint offset should be limited to 3/16 in. (5 mm).

This finish should be specified only when the product will not be visible in the completed structure, or when the function of the structure does not require an enhanced surface.

**Standard Grade** – Small surface holes caused by air bubbles (“bug-holes”), normal color variations, normal form joint marks, and minor chips and spalls should be considered acceptable.

No air holes (bug holes) larger than 1/2 in. (13 mm) in any direction should be permitted. Air holes between 1/4 and 3/8 in. (6 and 10 mm) in width that occur in high concentration (more than one per 2 in.<sup>2</sup> [1300 mm<sup>2</sup>]) should be filled. Large, unsightly surface blemishes or honeycombing should be repaired. The maximum allowable form joint offset should be limited to 1/8 in. (3 mm). This finish may be used where products are exposed to view but the function of the structure does not require a special finish. The surface should be suitable

for an applied textured coating but not necessarily suitable for painting.

This is the typical finish grade for all structural products.

**Finish Grade B** – All air holes over 1/4 in. (6 mm) in size should be filled. Air holes between 1/8 and 1/4 in. (3 and 6 mm) in width that occur in high concentration (more than one per 2 in.<sup>2</sup> [1300 mm<sup>2</sup>]) should be filled. Surface blemishes due to holes or dents in forms should be repaired. Discoloration should be permitted at form joints.

This finish may be used on visually exposed structural members such as columns or walls.

**Finish Grade A** – All surface blemishes should be repaired and/or filled with the exception of air holes 1/16 in. (2 mm) in width or smaller and form marks where the surface deviation is less than 1/16 in. (2 mm).

Discoloration should be allowed at form joints. All form joints should be ground smooth.

This surface is suitable for painting (especially with a textured or “sand” paint); however, some surface blemishes will be visible. If a surface with fewer imperfections than allowed for “Grade A” is needed, the requirements should be specified as a “special finish.”

### Exposed, Unformed Surface Finishes

These types of finishes are obtained by screeding and floating with additional hand finishing at projections. Normal color variations, minor indentations, minor chips, and spalls should be permitted. No major imperfections, honeycombing, or defects should be permitted.

Where uniformity or other special characteristics of exposed, unformed surface finishes are required, specifications should be clear on the expected results. Terms such as “steel trowel” or “smooth float” are insufficient to describe the quality of finish desired. While it may be generally understood that a “steel trowel” finish will be smooth, the degree of “flatness” of the surface can vary significantly. Similarly, the terms “light” and “heavy” broom finish, or “raked” finish may be subject to a wide range of interpretation. The extent to which float or trowel marks, variations of texture, or other surface blemishes will be permitted, should be specified. It is recommended that samples be used to establish the acceptance criteria for any exposed finish.

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# APPENDIX D

## Chuck Use and Maintenance Procedures

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 ensure proper performance. The following lists general procedures for using and maintaining chucks.

### A. Guidelines for Bed Crews:

1. Chucks should always be kept clean. Chucks not on the strand should never be thrown on the ground. All used chucks should be returned to the chuck-cleaning bench.
2. To secure strand, always use a chuck that is marked for use with the same size strand.
3. Visually inspect each chuck barrel before placing it on the strand. Visual inspection may consist of glancing down the center of the chuck to be certain all three wedges are in alignment and the chuck is clean.
4. To release a chuck from a piece of strand, grasp the chuck and push the barrel forward to remove the wedges. An alternative method would be to force the narrow end of a chuck removal tool into the barrel end of the assembled chuck. This will force the wedges back into the chuck and release it from the strand.
5. If the chuck cannot be released using the previous methods, cut the strand approximately two feet from each side of the chuck. Take the chuck and length of strand to the chuck cleaning room for proper removal. The chuck barrel should never be struck with any object to release the strand.
6. If the chuck comes off the strand easily, put the wedges back into the barrel.
7. All chucks and wedges should be cleaned, inspected, and lubricated prior to use.

### B. Guidelines for Chuck Maintenance and Inspection Personnel:

1. To remove a chuck that has been brought to the shop on a length of strand, use a chuck removal tool, a vise, and a sliding hammer.
  - a. Place the chuck removal tool over the strand and push the narrow end into the barrel end of the chuck.
  - b. Place the strand (with the chuck removal tool in place) upright in the vise so that the

chuck removal tool rests flat against the vise. Leave the wedges of the vise loose enough so the strand can move between them.

- c. Use the sliding hammer to strike the open end of the chuck. If necessary, another hammer can be used to strike the sliding hammer. Do not strike the chuck barrel with any hard object.
  - d. Striking the open end with a sliding hammer will force the chuck against the removal tool, pushing the wedges back into the barrel, and jarring the chuck loose. The chuck can then be removed either by pressing the removal tool into the barrel and sliding the chuck off the strand, or by disassembling the chuck.
2. To inspect and lubricate the chucks, use the following procedure:
    - a. Separate all chucks by size. Inspect each size of chuck completely before placing another size chuck on the bench.
    - b. Disassemble all chucks by removing the wedges and the rubber-retaining ring.
    - c. Use appropriate safety equipment, including eye protection and gloves, while cleaning chucks.
    - d. The chuck body can be cleaned with a tapered wire brush.
    - e. Before removing the rubber-retaining ring, the wedges can be cleaned with a motorized tapered nylon brush. Metallic wire brushes may damage the wedges and should never be used.
    - f. After cleaning, remove the rubber-retaining ring and inspect the wedges for signs of scratches, chipped threads, and score marks. Examine the rubber retaining rings for signs of splitting or damage. Inspect the barrels for signs of distress or excessive corrosion. *Discard all damaged parts* to assure they are not used in reassembly.
    - g. Clean and lubricate the barrels and allow approximately five minutes to dry. Lubricate the exterior of the jaw assembly.
    - h. Reassemble the chucks and store in a rack that is designed to keep the chucks clean and protected.
    - i. Repeat the process for each size of chuck.

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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 Appendix B.

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

<p><b>AGGREGATE ANALYSIS</b></p>	<p><b>SHEET</b> _____</p> <p><b>INSPECTOR</b> _____</p> <p><b>QC MANAGER</b> _____</p> <p><b>DATE</b> _____</p>
----------------------------------	---

Applicable Spec. _____		<b>FINE AGGREGATE</b>			Date Det. _____	
Sieve Size	Weight Ret. (Gms)	% Retained	% Passing	ASTM C33 Specs % Passing	Design Specifications	Remarks Tons Rep.
3/8"				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. = _____				

Applicable Spec. _____		<b>COARSE AGGREGATE</b>			Date Det. _____		
Sieve Size	Weight Ret. (Gms.)	% Retained	% Passing	ASTM C33 Size 57 % Passing	ASTM C33 Size 8 % Passing	Design Specifications	Remarks
1"				100	-		
3/4"				90 - 100	-		
1/2"				-	100		
3/8"				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. Supplier _____ Date Det. _____	Original Wt. of Sample _____ (At least 2.5 kg) Dry Wt. of Orig. Sample _____ = B Dry Wt. Sample After Washing _____ = C A (% Material Finer Than 200 Sieve) = $\frac{B-C}{B} \times 100 =$ _____

AGGREGATE MOISTURE CONTENT	ORGANIC IMPURITIES IN SAND (C40)												
Wt. Sample & Container (Wet) _____ (D) Wt. Sample & Container (Dry) _____ (E) Wt. of Container _____ (F) Wt. of Moisture (D-E) _____ (G) Net Dry Wt. of Sample (E-F) _____ (H)  % Moisture = $\frac{(G)}{H} \times 100 =$ _____ Speedy Moisture Test _____ %	<table style="width: 100%; border: none;"> <tr> <td style="width: 60%;">Circle Color of Sodium Hydroxide Solution</td> <td style="width: 40%;">Organic Plate No.</td> </tr> <tr> <td></td> <td style="text-align: center;">1</td> </tr> <tr> <td></td> <td style="text-align: center;">2</td> </tr> <tr> <td></td> <td style="text-align: center;">3 (standard)</td> </tr> <tr> <td></td> <td style="text-align: center;">4</td> </tr> <tr> <td></td> <td style="text-align: center;">5</td> </tr> </table> _____ Sand Supplier  _____ Date	Circle Color of Sodium Hydroxide Solution	Organic Plate No.		1		2		3 (standard)		4		5
Circle Color of Sodium Hydroxide Solution	Organic Plate No.												
	1												
	2												
	3 (standard)												
	4												
	5												



<h2 style="margin: 0;">CONCRETE TEST REPORT</h2> <p><b>Project</b> _____</p> <p><b>Cast #</b> _____</p>	<p><b>SHEET NO</b> _____</p> <p><b>INSPECTOR</b> _____</p> <p><b>QC MANAGER</b> _____</p> <p><b>DATE</b> _____</p>
---	--

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

CONCRETE YIELD COMPUTATION	AIR MEASUREMENT
<p><b>CEMENT</b> _____ <b>Wt. Container &amp; Concrete</b> _____</p> <p><b>Fine Aggregate</b> _____ <b>Wt. Container</b> _____</p> <p><b>Coarse Aggregate</b> _____ <b>Wt. Concrete</b> _____</p> <p><b>Admixture</b> _____ <b>Slump</b> _____</p> <p><b>Water No. Gals</b> ____ x 8.33 _____ <b>Entrained Air</b> _____</p> <p><b>Total Wt. per cu yd (A)</b> _____ <b>Wt. per cu ft (B)</b> _____</p> <p style="text-align: center;"><b>YIELD = <math>\frac{A}{B}</math> = _____ = _____</b></p>	<p><b>Aggregate Correction Factor (G)</b></p> <p><b>h<sub>1</sub></b> = _____</p> <p><b>h<sub>2</sub></b> = _____</p> <p><b>G</b> = _____</p> <p><b>Apparent Concrete Air Content (A<sub>1</sub>)</b></p> <p><b>h<sub>1</sub></b> = _____</p> <p><b>h<sub>2</sub></b> = _____</p> <p><b>A<sub>1</sub></b> = _____</p> <p><b>A (Air) = A<sub>1</sub> - G = _____</b></p>





**PRODUCT INSPECTION SHEET**

**POUR NO:** \_\_\_\_\_  
**BED NO:** \_\_\_\_\_  
**JOB NO:** \_\_\_\_\_  
**PRODUCT:** \_\_\_\_\_  
**FORM OIL:** \_\_\_\_\_  
**QC MANAGER:** \_\_\_\_\_

Date \_\_\_\_\_

Inspector \_\_\_\_\_

ID.	Job No.																			
	Piece No.																			
<b>SET-UP DETAILS</b>	Form Conditions and Cleanliness																			
	Design Length																			
	Form Set-Up Length																			
	As Cast Length																			
	Design Width (Flange)																			
	Form Set-Up Width (Flange)																			
	As Cast Width (Flange)																			
	Design Width (Stem)																			
	Form Set-Up Width (Stem)																			
	As Cast Width (Stem)																			
	Design Depth																			
	Form Set-Up Depth (Overall)																			
	As Cast Depth (Overall)																			
	Skew Distance																			
	End Details																			
	Strand Deflection Points																			
	Reinforcing Steel																			
	Plates																			
	Blockouts																			
	Inserts																			
Lifting Loops (Type, Quantity)																				
<b>FINISHED PRODUCT</b>	Vert. Out of Square (Max.)																			
	Horiz. Out of Spec (Max.)																			
	Calculated Initial Camber																			
	Measured Camber																			
	Age When Measured																			
	Longitudinal Alignment																			
	Sole Plates																			
	Miscellaneous Plates																			
	Chamfers																			
	Blockouts																			
	Transverse Rod Holes																			
	Lag Studs and Inserts																			
	Cracks																			
Surface Textures																				
Blocking																				
Finishing and Patching																				
Date Approval Stamp Applied																				
Dowel Holes																				
Strand Slippage																				
REMARKS:																				

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# APPENDIX F

## Certification Programs

### 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. In 1985, PCI implemented its Plant Quality Personnel Certification Program and in 1999 introduced the Certified Field Auditor and Field Qualification Programs for erectors of precast concrete (contact PCI for information about field certification programs).

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 assure 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. First, every plant must have at least one year of production experience. Each must document their specific practices in a custom Quality Systems 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. They are employed by a single consulting engineering firm, which ensures consistency for every plant.

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, MNL-116. The Table of Contents forms the basis of the grade sheet. During an audit, each chapter (Division) of the manual is graded separately. Auditing of 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 a more 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 parenthesis 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 the A and B, or, the A and C product groups (MNL-116) (see the detailed description BA and CA below)

**Product Categories** – The product groups are further divided into categories that define a product's reinforcement or the ways in which the products are manufactured or used.

#### Group 'A' Categories:

- AT – Miscellaneous Architectural Trim Units
- A1 – Architectural Precast Concrete Products

#### Group B Categories:

- B1 – Precast Bridge 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.

**Product Groups BA and CA** – Beginning with this Fourth Edition of MNL-116, an additional distinction for products and producers is available to the specifier. The new classification defines products that have architectural finishes applied to more traditional structural products. Before now, these products were not addressed in either MNL-116 or MNL-117. The special requirements for finish, texture, color, tolerances, and quality control are included at the end of each Division of this manual.

Qualified producers will be identified with the suffix “A” following their normal designation of B1 through B4 and C1 through C4. For example, if a precaster is certified to produce prestressed hollow-core wall panels with an exposed aggregate surface finish, the appropriate designation will be C2A. A bridge-products producer that manufactures prestressed fascia panels with an architectural finish for a bridge might be required to hold B2A certification or B4A if they also supply beams with deflected strands. The “A” (architectural finishes designation) may be applied to any “B” or “C” category. Refer to the Sample Specification at the end of this appendix for information about how to specify this and all of the other Groups and Categories.

A current listing of all PCI Certified Plants is published quarterly in PCI’s *ASCENT* magazine. A convenient searchable list is continuously updated on the Internet at: [www.pci.org](http://www.pci.org), or, contact PCI, Director of Certification Programs.

PCI is recognized as an approved Quality Assurance Agency by the Council of American Building Officials (see NER QA-105) which includes the:

- International Conference of Building Officials (ICBO)
- Building Officials and Code Administrators (BOCA)
- Southern Building Code Congress International, Inc. (SBBICI)

PCI Plant Certification is included in the MasterSpec of the American Institute of Architects and is required in the specifications of the following federal agencies:

- U.S. Army Corps of Engineers, Civil Works Division & Military Programs
- U.S. Naval Facilities Engineering Command (NAVFEC)
- Federal Aviation Administration
- General Services Administration
- U.S. Department of Agriculture, FSIS
- U.S. Department of Interior, Bureau of Reclamation

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 three levels of Plant Quality Personnel Certification.

**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.
- Prestressing concepts and tensioning procedures for straight strands, including basic elongation calculations.
- Basic concepts about concrete – water-cementitious material 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 in the 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:

- 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. Corrections 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 Levels 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. 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,
  - 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.

### Summary

The precast, prestressed concrete industry, through PCI, has taken bold steps to establish industry standards. The standards apply to personnel, to production and

operations, 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, contribute to continued customer satisfaction as well as reduced overall operating costs.

Certification by PCI assures 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 assessors.

PCI Plant and Personnel Certification are your most reliable means for qualifying your precast concrete producer. Specify PCI Certification Programs for your projects.

### Guide Qualifications Specification

**Manufacturer Qualifications for Structural Precast Concrete** – The precast concrete manufacturing plant shall be certified by the Precast/Prestressed Concrete Institute, Plant Certification Program. Manufacturers shall be certified at time of bidding. Certification shall be in the following product group(s) and category(ies):

*Select and insert one or more of the following applicable groups and categories.*

#### Group B – Bridge-Related Products

- B1 – Precast Bridge Products (no prestressed reinforcement)
- B2 – Prestressed Miscellaneous Bridge Products (not for the superstructure)
- B3 – Prestressed Straight-Strand Bridge Beams (for the superstructure)
- B4 – Prestressed Deflected-Strand Bridge Beams (for the superstructure)

#### Group BA – Bridge-Related Products that Require Architectural Finishes

- B1A, B2A, B3A, or, B4A

#### Group C – Commercial/Structural Products

- 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 CA – Commercial/Structural Products that Require Architectural Finishes

- C1A, C2A, C3A, or, C4A

#### *Notes to Specifiers:*

1. Guide specifications for product groups “A” and “G” are available from PCI.
2. Categories in Groups B and C are listed in ascending order. For example, a plant certified to produce products in Category C4 is automatically certified to produce products in the preceding Categories C1, C2 and C3. However, a plant certified to produce products in Category B2, while qualified for Category B1, is not qualified for Categories B3 or B4.
3. Categories in Groups BA and CA are also listed in ascending order. See Notes 4 & 5.
4. Groups BA and CA supercede Groups B and C in the same Category. For example, a plant certified to produce products in Category C4A is automatically certified to produce products in the preceding Categories C1A, C2A C3A and C1, C2, C3 and C4. However, a plant certified to produce products in Category B2A, while qualified for Categories B1A, B1 and B2, is not qualified for Categories B3A, B4A, B3 or B4.
5. For a specific project, there should be only one Product Group and Category selected. It should reflect the highest level of product on the project. For example, if a project required precast hollow-core slabs (C2) and double tees with harped strands (C4), only C4 should be specified. If the same project also required prestressed spandrels with an architectural finish (C3A), specify the highest number (C4) and add the suffix “A” to require a producer that has capability to provide special finishes. Therefore, the correct product group would be C4A.
6. Specify the most appropriate product group and category for the project. By selecting a higher category than necessary, or by adding “A” to a listing if not necessary to meet project requirements, unnecessary cost can result and available bidders restricted.

### **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 for Plant Quality Personnel, Level II. All personnel regularly engaged in the measuring, testing or evaluation of products or materials shall be similarly certified for Plant Quality Personnel, Level I.

# 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 production personnel be furnished with current reference literature and be encouraged to read and utilize it.

A minimum reference list should include applicable and current publications of the American Society for Testing and Materials; the American Concrete Institute; the Precast/Prestressed Concrete Institute; the Portland Cement Association; and similar agencies having pertinent applicable specifications dealing with the production of precast concrete.

### American Society for Testing and Materials (ASTM)

100 Barr Harbor Drive  
West Conshohocken, Pennsylvania 19428-2959  
www.astm.org

The ASTM Book of Standards contains specifications and test methods for most of the materials and standard practices used in the production of architectural precast concrete. It also contains specifications and methods of test for related materials. Some of the related standards are as follows.

### ASTM

#### Designation Title

A 27/A27M	Specification for Steel Castings, Carbon, for General Application
A 36/A36M	Specification for Carbon Structural Steel
A 47	Specification for Ferritic Malleable Iron Castings
A 47M	Specification for Ferritic Malleable Iron Castings (Metric)
A82	Specification for Steel Wire, Plain, for Concrete Reinforcement

A 108	Specification for Steel Bars, Carbon, Cold - Finished, Standard Quality
A 123	Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products
A 143	Practice for Safeguarding Against Embrittlement of Hot-Dip Galvanized Structural Steel Products and Procedure for Detecting Embrittlement
A 153	Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware
A 184/A184M	Specification for Fabricated Deformed Steel Bar Mats for Concrete Reinforcement
A 185	Specification for Steel Welded Wire Fabric, Plain, for Concrete Reinforcement
A 276	Specification for Stainless Steel Bars and Shapes
A 283/A283M	Specification for Low and Intermediate Tensile Strength Carbon Steel Plates
A 307	Specification for Carbon Steel Bolts and Studs, 60,000 PSI Tensile Strength
A 325	Specification for Structural Bolts, Steel, Heat Treated, 120/105 ksi Minimum Tensile Strength
A 370	Test Methods and Definitions for Mechanical Testing of Steel Products
A 416/A416M	Specification for Steel Strand, Uncoated Seven-Wire for Prestressed Concrete
A 421	Specification for Uncoated Stress-Relieved Steel Wire for Prestressed Concrete

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A 490	Specification for Heat-Treated Structural Bolts, 150 ksi Minimum Tensile Strength	A 706/A706M	Specification for Low-Alloy Steel Deformed and Plain Bars for Concrete Reinforcement
A 496	Specification for Steel Wire, Deformed, for Concrete Reinforcement	A 722	Specification for Uncoated High-Strength Steel Bar for Prestressing Concrete
A 497	Specification for Steel Welded Wire Fabric, Deformed, for Concrete Reinforcement	A 767/A767M	Specification for Zinc-Coated (Galvanized) Steel Bars for Concrete Reinforcement
A 500	Specification for Cold-Formed Welded and Seamless Carbon Steel Structural Tubing in Rounds and Shapes	A 775/A775M	Specification for Epoxy-Coated Reinforcing Steel Bars
A 572/A572M	Specification for High-Strength Low-Alloy Columbium-Vanadium Structural Steel	A 780	Practice for Repair of Damaged and Uncoated Areas of Hot-Dip Galvanized Coatings
A 615/A615M	Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement	A 884/A 884M	Specification for Epoxy-Coated Steel Wire and Welded Wire Fabric for Reinforcement
A 616/A616M	Specification for Rail-Steel Deformed and Plain Bars for Concrete Reinforcement	A 934/A934M	Specification for Epoxy-Coated Prefabricated Steel Reinforcing Bars
A 617/A617M	Specification for Axle-Steel Deformed and Plain Bars for Concrete Reinforcement	B 633	Specification for Electrodeposited Coatings of Zinc on Iron and Steel
A 641	Specification for Zinc-Coated (Galvanized) Carbon Steel Wire	B 766	Specification for Electrodeposited Coatings of Cadmium
A 641M	Specification for Zinc-Coated (Galvanized) Carbon Steel Wire (Metric)	C 29	Test Method for Bulk Density (Unit Weight) and Voids in Aggregate
A 666	Specification for Annealed or Cold-Worked Austenitic Stainless Steel Sheet, Strip, Plate, and Flat Bar	C 31	Practice for Making and Curing Concrete Test Specimens in the Field
A 675/A675M	Specification for Steel Bars, Carbon, Hot-Wrought, Special Quality, Mechanical Properties	C 33	Specification for Concrete Aggregates
		C 39	Test Method for Compressive Strength of Cylindrical Concrete Specimens

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C 40	Test Method for Organic Impurities in Fine Aggregates for Concrete	C 138	Test Method for Unit Weight, Yield, and Air Content (Gravimetric) of Concrete
C 42	Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete	C 142	Test Method for Clay Lumps and Friable Particles in Aggregates
C 67	Test Methods of Sampling and Testing Brick and Structural Clay Tile	C 143	Test Method for Slump of Hydraulic Cement Concrete
C 70	Test Method for Surface Moisture in Fine Aggregate	C 144	Specification for Aggregate for Masonry Mortar
C 88	Test Method for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate	C 150	Specification for Portland Cement
C 94	Specification for Ready-Mixed Concrete	C 171	Specification for Sheet Materials for Curing Concrete
C 109	Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or 50-mm Cube Specimens)	C 172	Practice for Sampling Freshly Mixed Concrete
C 117	Test Method for Materials Finer than No. 200 (77- $\mu$ m) Sieve in Mineral Aggregates by Washing	C 173	Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method
C125	Terminology Relating to Concrete and Concrete Aggregates	C 185	Test Method for Air Content of Hydraulic Cement Mortar
C 127	Test Method for Specific Gravity and Absorption of Coarse Aggregate	C 188	Test Method for Density of Hydraulic Cement
C 128	Test Method for Specific Gravity and Absorption of Fine Aggregate	C 191	Test Method for Time of Setting of Hydraulic Cement by Vicat Needle
C 131	Test Method for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine	C 192	Practice for Making and Curing Concrete Test Specimens in the Laboratory
C 136	Test Method of Sieve Analysis of Fine and Coarse Aggregates	C 204	Test Method for Fineness of Hydraulic Cement by Air Permeability Apparatus
		C 227	Test Method for Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar-Bar Method)
		C 231	Test Method for Air Content of

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	Freshly Mixed Concrete by the Pressure Method	C 494	Specification for Chemical Admixtures for Concrete
C 233	Test Method for Air-Entraining Admixtures for Concrete	C 566	Test Method for Total Evaporable Moisture Content of Aggregate by Drying
C 260	Specification for Air-Entraining Admixtures for Concrete	C 567	Test Method for Density of Structural Lightweight Concrete
C 295	Guide for Petrographic Examination of Aggregates for Concrete	C 578	Specification for Rigid, Cellular Polystyrene Thermal Insulation
C 309	Specification for Liquid Membrane-Forming Compounds for Curing Concrete	C 586	Test Method for Potential Alkali Reactivity of Carbonate Rocks for Concrete Aggregates (Rock Cylinder Method)
C 330	Specification for Lightweight Aggregates for Structural Concrete	C 591	Specification for Unfaced Preformed Rigid Cellular Polyisocyanurate Thermal Insulation
C 342	Test Method for Potential Volume Change of Cement-Aggregate Combinations	C 595	Specification for Blended Hydraulic Cements
C 370	Test Method for Moisture Expansion of Fired Whiteware Products	C617	Practice for Capping Cylindrical Concrete Specimens
C 403	Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance	C 618	Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Concrete
C 457	Test Method for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete	C 641	Test Method for Staining Materials in Lightweight Concrete Aggregates
C 469	Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression	C 642	Test Method for Density, Absorption, and Voids in Hardened Concrete
C 470	Specification for Molds for Forming Concrete Test Cylinders Vertically	C 666	Test Method for Resistance of Concrete to Rapid Freezing and Thawing
		C 685	Specification for Concrete Made by Volumetric Batching and Continuous Mixing

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C 702	Practice for Reducing Samples of Aggregate to Testing Size	C 1126	Specification for Faced or Unfaced Rigid Cellular Phenolic Thermal Insulation
C 805	Test Method for Rebound Number of Hardened Concrete	C 1157/C1157M	Performance Specification for Blended Hydraulic Cement
C 845	Specification for Expansive Hydraulic Cement	C 1218	Test Method for Water-Soluble Chloride in Mortar and Concrete
C881	Specification for Epoxy-Resin-Base Bonding Systems for Concrete	C 1231	Practice for Use of Unbonded Caps in Determination of Compressive Strength in Hardened Concrete Cylinders
C882	Standard Test Method for Bond Strength of Epoxy-Resin Systems Used with Concrete by Slant Shear	C 1240	Specification for Silica Fume for Use in Hydraulic-Cement Concrete and Mortar
C 917	Test Method for Evaluation of Cement Strength Uniformity from a Single Source	C 1252	Test Methods for Uncompacted Void Content of Fine Aggregate (as Influenced by Particle Shape, Surface Texture and Grading).
C 979	Specification for Pigments for Integrally Colored Concrete	C 1260	Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method)
C 989	Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars	D 75	Practice for Sampling Aggregates
C 1017	Specification for Chemical Admixtures for Use in Producing Flowing Concrete	D 4791	Test Method for Flat or Elongated Particles in Coarse Aggregate
C 1059	Specification for Latex Agents for Bonding Fresh to Hardened Concrete	E 4	Practices for Force Verification of Testing Machines
C 1064	Test Method for Temperature of Freshly Mixed Portland Cement Concrete	E 11	Specification for Wire Cloth Sieves for Testing Purposes
C 1077	Practice for Laboratories Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Laboratory Evaluation	E 105	Practice for Probability Sampling of Materials
C 1105	Test Method for Length Change of Concrete Due to Alkali-Carbonate Rock Reaction	E 329	Specification for Agencies Engaged in the Testing and/or Inspection of Materials Used in Construction

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## Reference Literature

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 only be used when shown by tests to be adequate for the intended usage and have been approved by the purchasing entity.

**American Concrete Institute**  
P.O. Box 9094  
Farmington Hills, MI 48333  
www.aci-int.org

1. Manual of Concrete Inspection, SP-2
2. Manual for Concrete Practice
  - Part 1 Materials and General Properties of Concrete
  - Part 2 Construction Practices and Inspection of Pavements
  - Part 3 Use of Concrete in Building - Design, Specifications, and Related Topics
  - Part 4 Bridges, Substructures, Sanitary, and Other Special Structures; Structural Properties
  - Part 5 Masonry; Precast Concrete; Special Processes

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

116R

Cement and Concrete Terminology

117R

Standard Specifications for Tolerances for Concrete Construction and Materials

201.2R

Guide to Durable Concrete

211.1

Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete

211.3

Standard Practice for Selecting Proportions for No-Slump Concrete

212.3R

Chemical Admixtures for Concrete

212.4

Guide for the Use of High-Range Water Reducing Admixtures (Superplasticizers) in Concrete

213R

Guide for Structural Lightweight Aggregate Concrete

214

Recommended Practice for Evaluation of Strength Test Results of Concrete

214.3R

Simplified Version of the Recommended Practice for Evaluation of Strength Test Results of Concrete

221R

Guide for Use of Normal Weight Aggregates in Concrete

221.2

Standard Practice for Selecting Proportions for Structural Lightweight 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 for Buildings

303R	Guide to Cast-in-Place Architectural Concrete Practice		
304R	Guide for Measuring, Mixing, Transporting, and Placing Concrete		
304.5	Batching, Mixing, and Job Control of Lightweight Concrete		
305R	Hot Weather Concreting		
306R	Cold Weather Concreting		
308	Standard Practice for Curing Concrete		
309R	Guide for Consolidation of Concrete		
309.1R	Behavior of Fresh Concrete During Vibration		
309.2R	Identification and Control of Visual Effects of Consolidation on Formed Concrete Surfaces		
311.5R	Guide for Concrete Plant Inspection and Field Testing of Ready-Mixed Concrete		
318	Building Code Requirements for Structural Concrete and Commentary		
363R	State-of-the-Art Report on High-Strength Concrete		
423.3R	Recommendations for Concrete Members Prestressed with Unbonded Tendons		
439.4R	Steel Reinforcement - Physical Properties and U.S. Availability		
517.2R	Accelerated Curing of Concrete at Atmospheric Pressure		
		<b>Precast/Prestressed Concrete Institute</b>	
		209 W. Jackson Blvd., Suite 500 Chicago, IL 60606-6938 E-mail: info@pci.org Website: www.pci.org	
		<b>PCI</b>	
		<b>Designation</b>	<b>Title</b>
		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
		SLP-122	PCI Safety and Loss Prevention Manual
		JR-307	Tolerances for Precast and Prestressed Concrete
		TN-3	Efflorescence on Precast Concrete
		<b>Portland Cement Association</b>	
		5420 Old Orchard Road Skokie, IL 60077 www.portcement.org	
		<b>PCA</b>	
		<b>Designation</b>	<b>Title</b>
		EB 1	Design and Control of Concrete Mixtures
		IS 214	Removing Stains and Cleaning Concrete Surfaces

**American Welding Society**  
 550 N.W. LeJeune Rd.  
 P.O. Box 351040  
 Miami, FL 33135  
 www.amweld.org

**AWS**

<b>Designation</b>	<b>Title</b>
A5.1	Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding
A 5.4	Specification for Stainless Steel Electrodes for Shielded Metal Arc Welding
A 5.5	Specification for Low Alloy Steel Covered Arc Welding Electrodes
A 5.18	Specification for Carbon Steel Filler Metals for Gas Shielded Arc Welding
A 5.20	Specification for Carbon Steel Electrodes for Flux Cored Arc Welding
A 5.28	Specification for Low Alloy Steel Filler Metals for Gas Shielded Arc Welding
A 5.29	Specification for Low Alloy Steel Electrodes for Flux Cored Arc Welding
B 1.11	Guide for Visual Inspection of Welds
B 2.1	Standard for Welding Procedure and Performance Qualification
C 5.4	Recommended Practices for Stud Welding
D 1.1	Structural Welding Code - Structural Steel
D 1.4	Structural Welding Code - Reinforcing Steel

QC 1	Specification for Qualification and Certification of Welding Inspectors
Z 49.1	Safety in Welding, Cutting and Allied Processes

**Canadian Standards Association**

178 Rexdale Boulevard  
 Etobicoke (Toronto)  
 Ontario, Canada M9W 1R3

**CSA**

<b>Designation</b>	<b>Title</b>
A 23.1/A23.2	Concrete Materials and Methods of Concrete Construction/Methods of Test for Concrete
A 23.2/14A	Potential Expansivity of Aggregates (Procedure for Length Change due to Alkali-Aggregate Reaction in Concrete Prisms)

**National Ready Mixed Concrete Association**

900 Spring Street  
 Silver Spring, MD 20910  
 www.nrmca.org

**NRMCA**

<b>Designation</b>	<b>Title</b>
Pub. #102	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>Concrete Plant Mixer Standards of Plant Mixer Manufacturers Division, CPMB</li> <li>Truck Mixer and Agitator Standards of the Truck Mixer Manufacturers</li> </ul>

- Bureau  
• Certification of Ready  
Mixed Concrete  
Production Facilities

**U.S. Bureau of Reclamation**

Denver Federal Center  
Denver, CO 80225

- Concrete Manual

**Concrete Reinforcing Steel Institute**

933 N. Plum Grove Road  
Schaumburg, IL 60173  
[www.crsi.org](http://www.crsi.org)

**CRSI**

**Designation**

**Title**

- Guidelines for Inspection  
and Acceptation of  
Epoxy-Coated  
Reinforcing Bars at the  
Job Site
- Field Handling  
Techniques for Epoxy-  
Coated Rebar at the Job  
Site
- Fusion Bonded Epoxy  
Coating Applicator Plant  
Certification Program

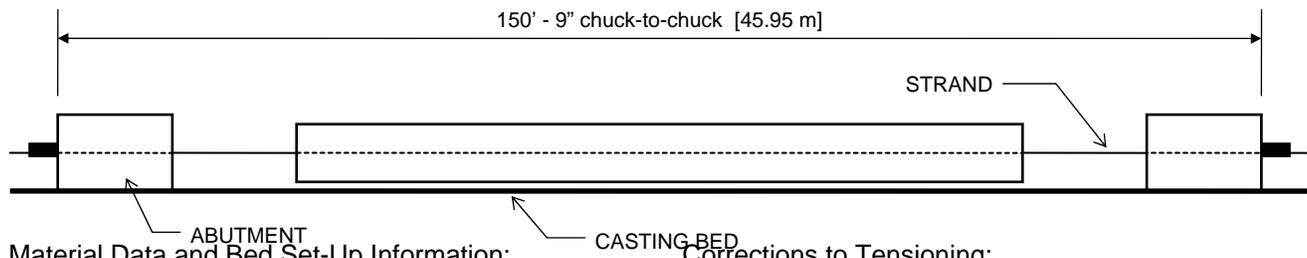
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# APPENDIX H

## 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,

$$A = 0.0850 \text{ in.}^2 [54.8 \text{ mm}^2]$$
$$E = 28,500,000 \text{ psi [196,507 MPa]}$$

*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:**

$$\text{Basic Elongation} = \frac{(\text{Force required beyond initial tension}) (\text{Length of strand between anchorages})}{(\text{Area of strand}) (\text{Modulus of elasticity})}$$

$$\text{Basic Elongation} = \frac{(17,250 - 1,500) \text{ lbs} \times 1809 \text{ in.}}{0.0850 \text{ in}^2 \times 285,000,000 \text{ psi}} = 11.76 \text{ in.} \left[ = \frac{(76.73 - 6.67) \text{ kN} \times 45.95 \text{ m}}{54.8 \text{ mm}^2 \times 196,500 \text{ MPa}} = 299 \text{ mm} \right]$$

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.  
*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.

$$\text{Force Adjustment} = 17,250 \text{ lbs} \times (0.01/10^\circ\text{F} \times 35^\circ\text{F}) = 604 \text{ lbs} \left[ = 76,728 \text{ N} \times 0.035 = 2,685 \text{ N} \right]$$

$$\text{Elongation Adjustment} = \frac{604 \text{ lbs.} \times 1,809 \text{ in.}}{0.085 \text{ in}^2 \times 28,500,000 \text{ psi}} = 0.451 \text{ in.} \left[ = \frac{2,685 \text{ N} \times 45.95 \text{ m}}{54.8 \text{ mm}^2 \times 196,507 \text{ MPa}} = 11 \text{ mm} \right]$$

**Total Force Required** = 17,250 + 502 + 604 = 18,356 lbs [76,728 + 2,335 + 2,685 = 81,748 N]

**A1. Pretensioned Straight Strand with Abutment Anchorages (cont'd)**

**Elongation Computation Summary:**

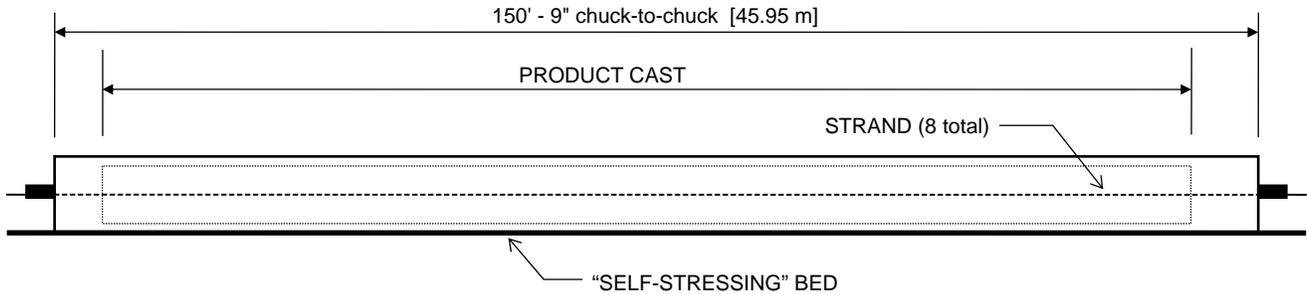
	Gross Theoretical Elongation		Net Theoretical Elongation	
Basic Elongation	11.76 in.	299 mm	11.76 in.	299 mm
Abutment Rotation	0.25	6	0.25	6
Dead End Seating	0.125	3	0.125	3
Live End Seating	0.375	10	0.0	0
Temperature Adjustment	0.451	11	0.451	11
Total Elongation	12.961 in.	329 mm	12.586 in.	319 mm
Rounded	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 strand 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. + 1/16 in.) [6 mm + 1.6 mm] per strand.

$$\text{Force Adjustment} = \frac{0.3125 \text{ in.} \times 15,750 \text{ lbs}}{11.76 \text{ in.}} = 419 \text{ lbs} \left[ = \frac{8 \text{ mm} \times 70,056 \text{ N}}{299 \text{ mm}} = 1,864 \text{ N} \right]$$

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.

**Total Force Required** = 17,250 + 419 + 502 = 18,171 lbs [76,728 + 1,864 + 2,335 = 80,825 N]

**A2. Pretensioned Straight Strand in a “Self-Stressing” Form (cont’d)**

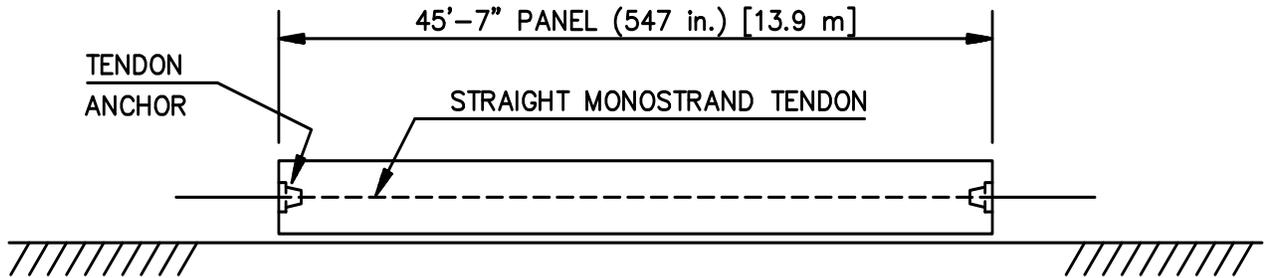
**Elongation Computation Summary:**

	Gross Theoretical Elongation		Net Theoretical Elongation	
Basic Elongation	11.76 in.	299 mm	11.76 in.	299 mm
Form Shortening	0.312	7.6	0.312	7.6
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	12.572 in.	319.6 mm	12.197 in.	309.6 mm
Rounded	12-5/8 in.	320 mm	12-3/16 in.	310 mm
Tolerance Limits	-5% = 12 in.	304 mm	-5% = 11-9/16 in.	294 mm
	+5% = 13-1/4 in.	336 mm	+5% = 12-13/16 in.	326 mm

Use Gross Theoretical Elongation for monitoring travel of strand tensioning jack ram, and compare to 18,171 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:  
 $f'_{ci} = 3,000 \text{ psi [20.7 MPa]}$   
 $E_{ci} = 33 (150)^{1.5} (\sqrt{3,000 \text{ psi}}) = 3,320,561 \text{ psi}$

$$\left[ \frac{0.043 (2,400 \text{ kg/m}^3)^{1.5} (\sqrt{20.7 \text{ MPa}})}{23,000 \text{ MPa}} \right] =$$

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.

## APPENDIX H

## Sample Tensioning Data Calculations

### 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,

$$\alpha = 0 \text{ for a straight tendon, and } \frac{P_D}{P_S} = e^{-(0.0014 \times 45.583 \text{ ft})} = 0.938 \quad [e^{-(0.0046 \times 13.9 \text{ m})} = 0.938]$$

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:

$$\begin{aligned} \text{Force Adjustment} &= 28,910 \times 0.031 = 896 \text{ lbs} [128.6 \text{ kN} \times 0.031 = 3986 \text{ N}] \\ \text{Elongation Adjustment} &= 3.25 \times 0.031 = 0.101 \text{ in.} [82.7 \text{ mm} \times 0.031 = 3 \text{ mm}] \end{aligned}$$

**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.

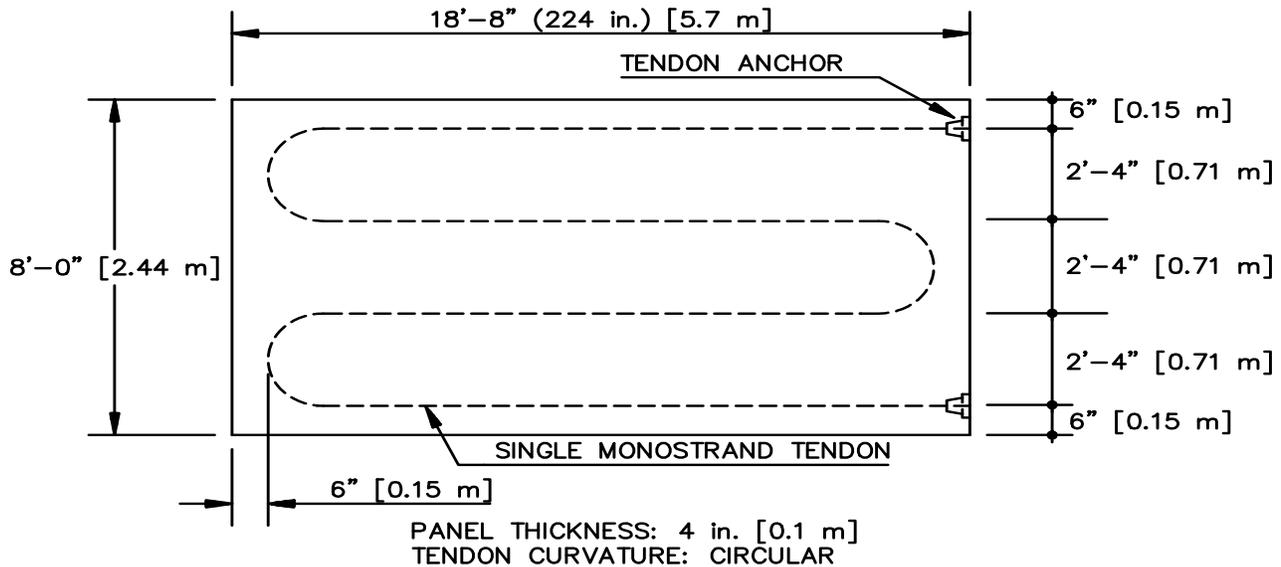
#### Elongation Computation Summary:

	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.

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,  
 $A = 0.1530 \text{ in.}^2$  [98.71 mm<sup>2</sup>]  
 $E = 28,500,000 \text{ psi}$  [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]  
 $\mu$  (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 lbs x 0.70 = 28,910 lbs  
[183.7 kN x 0.70 = 128.6 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,

$$\begin{aligned} \frac{P_D}{P_S} &= e^{-(0.0007 \times 75.67 \text{ ft} + 0.05 \times 9.42)} = 0.59 \\ \text{Curvature} = \alpha &= \pi(3) = 9.42 \text{ radians} \\ &\left[ e^{-(0.0023 \times 23.1 \text{ m} + 0.05 \times 9.42)} = 0.59 \right] \end{aligned}$$

Average strand force =  $(1 + 0.59)/2 = 0.795$ , 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:

Elongation Adjustment =  $5.40 \times 0.115 = 0.621$  in. [137 mm  $\times$  0.115 = 15.8 mm]  
 Force Adjustment =  $28,910 \times 0.115 = 3,325$  lbs [128.6 kN  $\times$  0.115 = 14.79 kN]

**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.

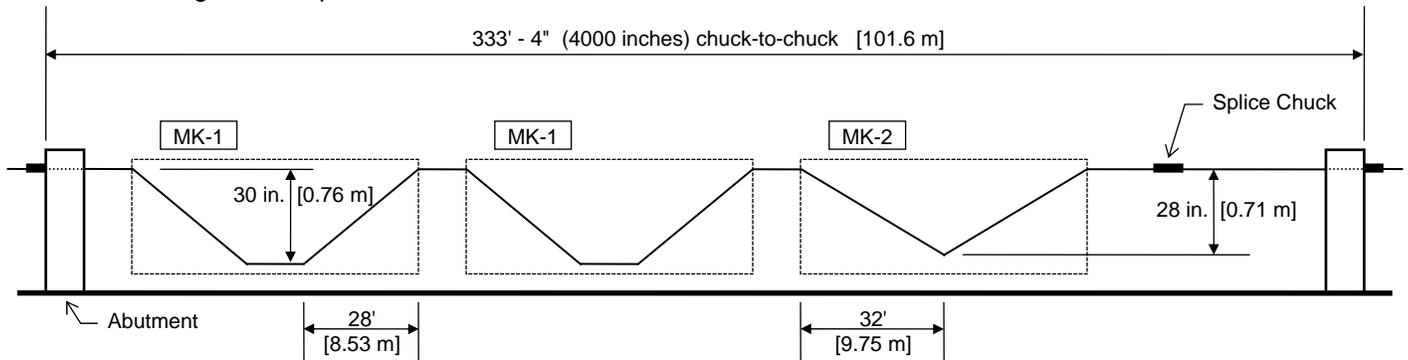
**Elongation Computation Summary:**

	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.

**D1. Pretensioned Harped Strand - Tensioned in the Harped Position**

The following example details the method for calculating the tensioning data for strand tensioned in the draped position in an abutment anchorage set-up. Adjustments for abutment rotation, anchor wedge seating loss, splice chuck seating, and temperature variation are shown.



**Material Data and Bed Set-Up Information:**

1. Size and type of strand: 1/2 in. [13 mm] diameter, 270K [1860 MPa], low-relaxation.
2. Physical characteristics of strand:  
The average values being used by the plant are,  
 $A = 0.1531 \text{ in.}^2$  [98.8 mm<sup>2</sup>]  
 $E = 28,600,000 \text{ psi}$  [197,197 MPa]  
*See note in Example A1 regarding strand properties.*
3. Initial load of 3,000 lbs [13.344 kN] has proven adequate on strand in this bed in the past.
4. Strand is to be tensioned to 75% of ultimate,  
 $41,300 \text{ lbs} \times 0.75 = 30,975 \text{ lbs}$   
 $[183.7 \text{ kN} \times 0.75 = 137.8 \text{ kN}]$

**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 1/4 in. [6 mm] based on past history. Over-pull of 1/4 in. [6 mm] is required.
- d. Splice Chuck Anchor Wedge Seating  
Based on ongoing monitoring, slippage of 1/8 in. [3 mm] each side of splice, or 1/4 in. [6 mm] total is expected after initial tensioning.
- e. Temperature Variation  
Strands will have a temperature of 40°F [4.5°C] when tensioned. The concrete is expected to be at 70°F [21°C] based on current production monitoring, giving an anticipated change of +30°F [16.5°C].
- f. Friction from Hold Down Anchors  
Depending on the design of hold down anchor hardware, friction between the deflected strand and hold down hardware may be a significant source of friction. For this example, hardware is assumed to result in negligible friction.

**D1. Pretensioned Harped Strand - Tensioned in the Harped Position (cont'd)**

**Tensioning Computations:**

$$\text{Basic Elongation} = \frac{(\text{Force required beyond initial tension}) (\text{Length of strand between anchorages})}{(\text{Area of strand}) (\text{Modulus of elasticity})}$$

Calculate length of strand:

Added strand length in two MK-1 set-ups;

$$\left( \sqrt{(336 \text{ in.})^2 + (30 \text{ in.})^2} - 336 \text{ in.} \right) \times 4 = 5.35 \text{ in.} \quad \left[ \left( \sqrt{(8.53 \text{ m})^2 + (0.76 \text{ m})^2} - 8.53 \text{ m} \right) \times 4 = 135 \text{ mm} \right]$$

Added strand length in one MK-2 set-up;

$$\left( \sqrt{(384 \text{ in.})^2 + (28 \text{ in.})^2} - 384 \text{ in.} \right) \times 2 = 2.03 \text{ in.} \quad \left[ \left( \sqrt{(9.75 \text{ m})^2 + (0.71 \text{ m})^2} - 9.75 \text{ m} \right) \times 2 = 52 \text{ mm} \right]$$

$$\text{Total strand length; } 4000 \text{ in.} + 5.35 \text{ in.} + 2.03 \text{ in.} = 4007.38 \text{ in.} \quad [101.6 \text{ m} + 0.135 \text{ m} + 0.052 \text{ m} = 101.78 \text{ m}]$$

$$\begin{aligned} \text{Basic Elongation} &= \frac{(30,975 - 3,000) \text{ lbs} \times 4007.38 \text{ in.}}{0.1531 \text{ in}^2 \times 28,600,000 \text{ psi}} = 25.60 \text{ in.} \\ &= \frac{(137.8 - 13.34) \text{ kN} \times 101.79 \text{ m}}{98.8 \text{ mm}^2 \times 197,197 \text{ MPa}} = 650 \text{ mm} \end{aligned}$$

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.  
*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 1/4 in. [6 mm]. Adjust force accordingly.

$$\text{Force Adjustment} = \frac{0.25 \text{ in.} \times 27,975 \text{ lbs}}{25.60 \text{ in.}} = 273 \text{ lbs} \quad \left[ = \frac{6.4 \text{ mm} \times 124,433 \text{ N}}{650 \text{ mm}} = 1,220 \text{ N} \right]$$

- d. Splice Chuck Anchor Wedge Seating Loss: Add 1/4 in. [6 mm] to elongation. No adjustment to force is required.

**D1. Pretensioned Harped Strand - Tensioned in the Harped Position (cont'd)**

e. 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.

$$\text{Force Adjustment} = 30,975 \text{ lbs} \times (0.01/10 \text{ }^\circ\text{F} \times 30 \text{ }^\circ\text{F}) = 929 \text{ lbs} \quad [= 137.8 \text{ kN} \times 0.03 = 4,134 \text{ N}]$$

$$\begin{aligned} \text{Elongation Adjustment} &= \frac{929 \text{ lbs} \times 4,007.38 \text{ in.}}{0.1531 \text{ in}^2 \times 28,600,000 \text{ psi}} = 0.85 \text{ in.} \\ &= \left[ \frac{4,134 \text{ N} \times 101.84 \text{ m}}{98.8 \text{ mm}^2 \times 197,197 \text{ MPa}} = 21.6 \text{ mm} \right] \end{aligned}$$

**Total Force Required** = 30,975 + 273 + 929 = 32,177 lbs [137.8 + 1.220 + 4.134 = 143,1 kN]

*Note that if only a portion of the bed is used, and only that portion is covered and heated during the curing cycle, a proportional decrease in the over-pull force and elongation adjustment required for temperature should be used.*

**Elongation Computation Summary:**

	Gross Theoretical Elongation		Net Theoretical Elongation	
Basic Elongation	25.60 in.	650 mm	25.60 in.	650 mm
Abutment Rotation	0.25	6	0.25	6
Dead End Seating	0.125	3	0.125	3
Live End Seating	0.25	6	0.0	0
Splice Chuck Seating	0.25	6	0.25	6
Temperature Adjustment	0.85	21.6	0.85	21.6
Total Elongation	27.33 in.	692.6 mm	27.08 in.	686.5 mm
Rounded	27-3/8 in.	693 mm	27-1/8 in.	687 mm
Tolerance Limits	-5% = 26 in.	659 mm	-5% = 25-3/4 in.	653 mm
	+5% = 28-3/4 in.	728 mm	+5% = 28-1/2 in.	721 mm

Use Gross Theoretical Elongation for monitoring travel of strand tensioning jack ram, and compare to 32,177 lbs [143,081 N] force. Use Net Theoretical Elongation for comparison, after seating of live end anchorage, against movement of mark on strand from initial tension reference.

**Check Anchor Load At Deflected Strand Points:**

The anchor force at the deflect points should always be checked against the safe working capacity of the hardware being used. *Note that the total anchor load (the sum for all strand in the set-up) needs to be checked.*

For angles of less than 10 degrees, the sine and tangent functions are nearly equal. Therefore, it is common practice to use the tangent in calculating the anchor resistance required rather than computing the deflected strand length.

MK-1 set-up;      End Anchor Load =  $\frac{30 \text{ in.}}{336 \text{ in.}} \times 32,177 \text{ lbs} = 2,873 \text{ lbs} \quad \left[ \frac{0.76 \text{ m}}{8.53 \text{ m}} \times 143,047 \text{ N} = 12,745 \text{ N} \right]$   
 Center Anchor Load = End Anchor Load

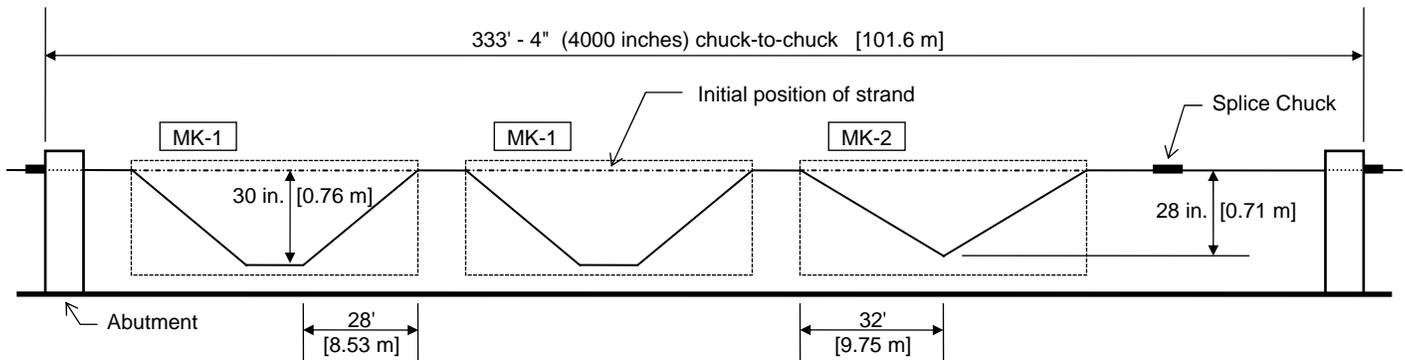
MK-2 set-up;      End Anchor Load =  $\frac{28 \text{ in.}}{384 \text{ in.}} \times 32,177 \text{ lbs} = 2,346 \text{ lbs} \quad \left[ \frac{0.71 \text{ m}}{9.75 \text{ m}} \times 143,047 \text{ N} = 10,417 \text{ N} \right]$   
 Center Anchor Load = 2 × 2,346 lbs = 4,692 lbs [2 × 10,417 N = 20,834 N]

## APPENDIX H

## Sample Tensioning Data Calculations

### D2. Pretensioned Harped Strand - Straight Strand Lifted or Deflected Into Final Position

The following example details the method of calculating the tensioning data for a straight strand subsequently realigned to a draped position. Adjustments for abutment rotation, anchor wedge seating loss, splice chuck seating, and temperature variation are shown.



Material data and bed set-up information are the same as in Example D1.

#### Tensioning Computations:

$$\text{Basic Elongation} = \frac{(\text{Force required beyond initial tension}) (\text{Length of strand between anchorages})}{(\text{Area of strand}) (\text{Modulus of elasticity})}$$

$$\begin{aligned} \text{Basic Elongation} &= \frac{(30,975 - 3,000) \text{ lbs} \times 4000 \text{ in.}}{0.1531 \text{ in}^2 \times 28,600,000 \text{ psi}} = 2556 \text{ in.} \\ &= \left[ \frac{(137.8 - 13.34) \text{ kN} \times 101.6 \text{ m}}{98.8 \text{ mm}^2 \times 197,197 \text{ MPa}} = 649 \text{ mm} \right] \end{aligned}$$

Determine added length of strand due to depressing into final position (see Example D1 for calculation):

Added strand length in two MK-1 set-ups; 5.35 in. [135 mm]

Added strand length in one MK-2 set-up; 2.03 in. [52 mm]

Required Measured Elongation = 25.56 - 5.35 - 2.03 = 18.18 in. [649 - 135 - 52 = 462 mm]

$$\begin{aligned} \text{Required Measured Tensioning Force} &= \frac{18.18 \text{ in.} \times 0.1531 \text{ in}^2 \times 28,600,000 \text{ psi}}{4000 \text{ in.}} = 19,901 \text{ lbs} \\ &= \left[ \frac{462 \text{ mm} \times 98.8 \text{ mm}^2 \times 197,197 \text{ MPa}}{101.6 \text{ m}} = 88.52 \text{ kN} \right] \end{aligned}$$

Theoretical Elongation = Required Measured Elongation combined with appropriate corrections.

**D2. Pretensioned Harped Strand - Straight Strand Lifted or Deflected Into Final Position (cont'd)**

**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. (Same as Example D1.)
- b. Dead End Anchor Wedge Seating: Add 1/8 in. [3 mm] to elongation. No adjustment to force is required. (Same as Example D1.)
- c. Live End Anchor Wedge Seating: Over-pull by 1/4 in. [6 mm]. Adjust force accordingly.

$$\text{Force Adjustment} = \frac{0.25 \text{ in.} \times 19,901 \text{ lbs}}{18.18 \text{ in.}} = 274 \text{ lbs.} \left[ = \frac{6.4 \text{ mm} \times 88.52 \text{ kN}}{462 \text{ mm}} = 1,218 \text{ N} \right]$$

- d. Splice Chuck Anchor Wedge Seating Loss: Add 1/4 in. [6 mm] to elongation. No adjustment to force is required. (Same as Example D1.)
- e. 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.

$$\text{Force Adjustment} = 19,901 \text{ lbs} \times (0.01/10 \text{ }^\circ\text{F} \times 30^\circ\text{F}) = 597 \text{ lbs}$$

$$\left[ = 88.52 \text{ kN} \times 0.03 = 2,656 \text{ N} \right]$$

$$\text{Elongation Adjustment} = \frac{597 \text{ lbs} \times 4000 \text{ in.}}{0.1531 \text{ in}^2 \times 28,600,000 \text{ psi}} = 0.55 \text{ in.}$$

$$\left[ = \frac{2,656 \text{ N} \times 101.6 \text{ m}}{98.8 \text{ mm}^2 \times 197,197 \text{ MPa}} = 14 \text{ mm} \right]$$

**Total Force Required** = 19,901 + 274 + 597 = 20,722 lbs [88.52 + 1.218 + 2.656= 92.39 kN]

*Note that if only a portion of the bed is used, and only that portion is covered and heated during the curing cycle, a proportional decrease in the over-pull force and elongation adjustment required for temperature should be used.*

**Elongation Computation Summary:**

	Gross Theoretical Elongation		Net Theoretical Elongation	
Basic Elongation	18.18 in.	462 mm	18.18 in.	462 mm
Abutment Rotation	0.25	6	0.25	6
Dead End Seating	0.125	3	0.125	3
Live End Seating	0.25	6	0.0	0
Splice Chuck Seating	0.25	6	0.25	6
Temperature Adjustment	0.55	12	0.55	12
Total Elongation	19.61 in.	495 mm	19.29 in.	489 mm
Rounded	19-5/8 in.	495 mm	19-1/4 in.	489 mm
Tolerance Limits	-5% = 18-5/8 in.	470 mm	-5% = 18-3/8 in.	465 mm
	+5% = 20-9/16 in.	520 mm	+5% = 20-1/4 in.	513 mm

**D2. Pretensioned Harped Strand - Straight Strand Lifted or Deflected Into Final Position (cont'd)**

Use Gross Theoretical Elongation for monitoring travel of strand tensioning jack ram, and compare to 20,722 lbs [92.39 kN] force. Use Net Theoretical Elongation for comparison, after seating of live end anchorage, against movement of mark on strand from initial tension reference.

**Check Anchor Load at Deflected Strand Points:**

The anchor load at the harping points should always be checked against the safe working capacity of the hardware being used. *Note that the total anchor load (the sum for all strands in the set-up) needs to be checked.*

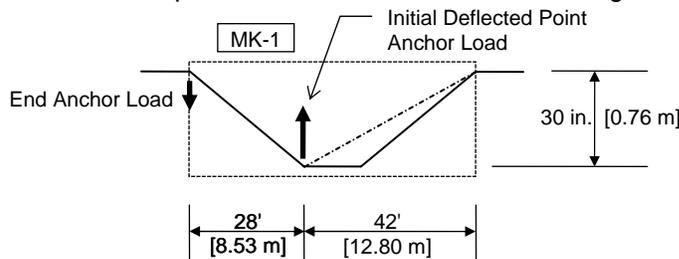
As the strand is forced into its final position (usually with a hydraulic ram) the force in the strand increases due to the increased strain. The maximum anchor load should therefore be calculated based on the final force in the strand.

$$\text{Final strand force} = (30,975 \times 1.03) + 274 = 32,178 \text{ lbs} \quad [(137,800 \times 1.03) + 1,218 = 143,152 \text{ N}]$$

For angles of less than 10 degrees, the sine and tangent functions are nearly equal. Therefore, it is common practice to use the tangent in calculating the anchor resistance required rather than computing the deflected strand length.

MK-1 set-up:

In a "2-point" deflected pattern, as shown in the diagram for the "MK-1" set-up, the strand is usually deflected at each point independently. The maximum load occurs when the first point is deflected as shown in the diagram below.



$$\text{End Anchor Load} = \frac{30 \text{ in.}}{336 \text{ in.}} \times 32,178 \text{ lbs} = 2,873 \text{ lbs} \quad \left[ \frac{0.76 \text{ m}}{8.53 \text{ m}} \times 143,152 \text{ N} = 12,754 \text{ N} \right]$$

$$\begin{aligned} \text{Initial Deflect Point Anchor Load} &= \left( \frac{30 \text{ in.}}{336 \text{ in.}} + \frac{30 \text{ in.}}{504 \text{ in.}} \right) \times 32,178 \text{ lbs} = 4,788 \text{ lbs} \\ &= \left( \frac{0.76 \text{ m}}{8.53 \text{ m}} + \frac{0.76 \text{ m}}{12.80 \text{ m}} \right) \times 143,152 \text{ N} = 21,254 \text{ N} \end{aligned}$$

MK-2 set-up:

$$\text{End Anchor Load} = \frac{28 \text{ in.}}{384 \text{ in.}} \times 32,178 \text{ lbs} = 2,346 \text{ lbs} \quad \left[ \frac{0.71 \text{ m}}{9.75 \text{ m}} \times 143,152 \text{ N} = 10,417 \text{ N} \right]$$

$$\text{Center Anchor Load} = 2 \times 2,346 \text{ lbs} = 4,692 \text{ lbs} \quad [2 \times 10,417 \text{ N} = 20,834 \text{ N}]$$

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# APPENDIX I

## 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 1 ft. = 0.3048 m = 304.8 mm	<b>Length</b>	1 m = 39.37 in. 1 m = 3.2808 ft
1 in <sup>2</sup> = 645.2 mm <sup>2</sup> 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> 1 m <sup>2</sup> = 10.76 ft <sup>2</sup>
1 in <sup>3</sup> = 16,387 mm <sup>3</sup> 1 ft <sup>3</sup> = 2.832 x 10 <sup>-2</sup> m <sup>3</sup> 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> 1 m <sup>3</sup> = 35.311 ft <sup>3</sup> 1 m <sup>3</sup> = 1.308 yd <sup>3</sup>
1 lb = 4.448 N 1 k = 4.448 kN 1 lb/in = 175.1 N/m 1 lb/ft = 14.59 N/m 1 k/ft = 14.59 kN/m	<b>Force and Force per Unit Length</b>	1 N = 0.225 lb 1 kN = 0.225 k 1 N/m = 5.711 x 10 <sup>-3</sup> lb/in 1 N/m = 0.0685 lb/ft 1 kN/m = 0.0685 k/ft
1 psi = 6.895 kPa 1 ksi = 6.895 MPa 1 psf = 47.88 Pa	<b>Stress and Modulus of Elasticity</b>	1 kPa = 0.145 psi 1 MPa = 0.145 ksi 1 Pa = 0.0209 psf
1 pcf = 16.02 kg/m <sup>3</sup> 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> 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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