

Manual for

QUALITY CONTROL

for Plants and Production of

STRUCTURAL PRECAST CONCRETE PRODUCTS

FOURTH EDITION

MNL-116-99



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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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Sidney Freedman of the Precast/Prestressed Concrete Institute for collecting and providing much of the initial technical material used to develop this edition.

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/ft³ (1121 kg/m³) 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 μ m) sieve; or that portion of an aggregate passing the No. 4 (4.75 mm) sieve and predominately retained on the No. 200 (75 μ 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/ft³ (1440 to 1850 kg/m³) 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

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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*.

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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*.

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.

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.

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.

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

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

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

Commentary

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

C2.1.1 General

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

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

C2.1.2 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.

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

C2.2.1 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.

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.

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.

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.

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

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.

Standard

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 ⁽²⁾	Minimum Temperature ^{(1) (2) (3)} °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

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 (9.2×10^{-6} in./in./°F [16.6×10^{-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.

Standard**Commentary**

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

Standard

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.

Table 2.3.2 Welding Reinforcing Bars

Carbon Equivalent ⁴ Range, %	Size of Reinforcing Bar	Minimum Preheat and Interpass Temperatures ^{1, 2, 3, 6}	
		°F	°C
0.40 max.	Up to 11 (36) inclusive 14 (43) and 18 (57)	None ⁵ 50	10
0.41 – 0.45 inclusive	Up to 11 (36) inclusive 14 (43) and 18 (57)	None ⁵ 100	40
0.46 – 0.55 inclusive	Up to 6 (19) inclusive 7 (22) to 11 (36) inclusive 14 (43) and 18 (57)	None ⁵ 100 200	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.

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:

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

If mill test reports are not available, chemical analysis

Commentary

% 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.

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.

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.

Standard

Commentary

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.

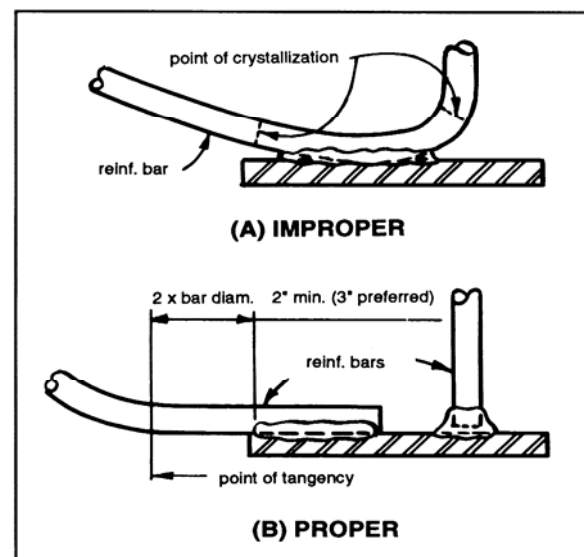


Fig. C2.3.2. Improper and proper methods of welding reinforcing bars.

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.

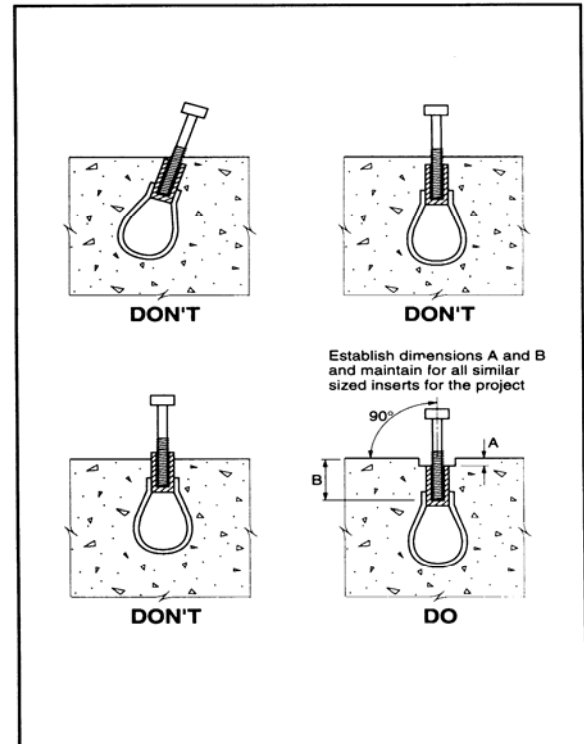


Fig. C2.5.1. Placing of inserts.

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

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.

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.

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

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.

Commentary

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.