ACI 533R-11

Guide for Precast Concrete Wall Panels

Reported by ACI Committee 533

American Concrete Institute®

First Printing
March 2012

American Concrete Institute®
Advancing concrete knowledge

Guide for Precast Concrete Wall Panels

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

www.concrete.org

ISBN 978-0-87031-756-9

Guide for Precast Concrete Wall Panels

Reported by ACI Committee 533

Brian D. Miller, Chair

David Wan, Secretary

George F. Baty
Harry A. Chambers
Aaron W. Fink
Sidney Freedman
Harry A. Gleich
Allan R. Kenney
Benjamin Lavon
Donald F. Meinheit
Larbi M. Sennour
Venkatesh Seshappa
Ava Shypula

Thomas J. Grisinger, Consulting Member
Weilan Song, Consulting Member

This guide presents recommendations for precast concrete wall panels. It should be used with ACI 318-08, "Building Code Requirements for Structural Reinforced Concrete," which is legally binding when adopted by the local authority. This guide discusses the basic principles of design, tolerances, materials, fabrication, installation, quality requirements, and testing.

Keywords: admixtures; aggregates; architectural concrete; coatings; cracking (fracturing); curing; deflection; design; drying shrinkage; fabrication; formwork; inspection; installation joints (junction); precast concrete panels; repairs; sandwich panels; sealants; structural design; surface defects; tolerances; volume change.

CONTENTS

Chapter 1—General considerations, p. 2
1.1—Introduction
1.2—Scope
1.3—Responsibility
1.4—Aesthetic considerations

Chapter 2—Notation and definitions, p. 4
2.1—Notation
2.2—Definitions

Chapter 3—Wall panel design, p. 4
3.1—Introduction
3.2—Design guidelines
3.3—Effective dimensions
3.4—Limiting dimensions
3.5—Serviceability
3.6—Connections
3.7—Architectural features

Chapter 4—Tolerances, p. 8
4.1—General
4.2—Reasons for tolerances
4.3—Role of the engineer/architect
4.4—Product tolerances for wall panels
4.5—Installation tolerances for wall panels
4.6—Interfacing considerations
4.7—Clearances and tolerances for constructibility

Chapter 5—Materials, p. 13
5.1—Introduction
5.2—Portland cement
5.3—Aggregates for structural or backup concrete
5.4—Facing aggregates
5.5—Admixtures
5.6—Insulating materials and wythe connectors for insulated sandwich walls
5.7—Reinforcement
5.8—Inserts and miscellaneous hardware
5.9—Curing materials and sealers
5.10—Joint sealants and fillers

ACI 533R-11 supersedes ACI 533R-93 and was adopted and published March 2012.

5.11—Chemical retarders
5.12—Form release agents

Chapter 6—Panel fabrication and delivery, p. 19
6.1—General requirements
6.2—Molds (forms and casting beds)
6.3—Concrete proportioning and mixing
6.4—Reinforcement and wythe connectors
6.5—Concrete placement
6.6—Surface finishes
6.7—Concrete curing
6.8—Storage
6.9—Delivery

Chapter 7—Installation, p. 31
7.1—Planning and preparation
7.2—Unloading and handling
7.3—Job site storage
7.4—Installation
7.5—Tolerances
7.6—Cleaning
7.7—Patching and repairing

Chapter 8—Quality requirements and tests, p. 41
8.1—Introduction
8.2—Unacceptable defects
8.3—Structural adequacy
8.4—Prestressing
8.5—Materials
8.6—Testing fresh concrete
8.7—Testing hardened concrete
8.8—Documentation

Chapter 9—References, p. 45

CHAPTER 1—GENERAL CONSIDERATIONS

1.1—Introduction

The widespread popularity of concrete as a building material can be attributed to the availability, favorable properties, and geographic distribution of its naturally-occurring mineral constituents. Concrete is easily formed and molded, comparatively economical, and durable in its finished state. Architectural precast panel use has increased because of the nature of concrete as a material and the fact that prefabricated components add to construction efficiency. By exposing decorative aggregates, using veneer facing materials, and by varying sizes, shapes, and textures of panels, the engineer/architect can respond creatively to client needs.

1.2—Scope

This document provides guidelines for specifying, planning, designing, fabrication, and erecting precast concrete wall panels. Although the focus is on precast wall panels produced in established precasting plants, site precasting is an option that has been used successfully. Tilt-up concrete, as discussed in ACI 551.1R-05, is a variation of site precasting. ACI 533R should aid in establishing and maintaining quality site fabrication as well as plant fabrication of precast wall panels.

This guide covers non-load-bearing or load-bearing panels, fabricated of normal or lightweight concrete. Panels may be one of the following types:

- Solid
- Insulated (sandwich)
- Ribbed
- Hollow-core
- Sculptured

In addition to reinforced panels, lightly prestressed (effective prestress, after all losses, between 150 and 225 psi [1.0 and 1.7 MPa]) and prestressed panels are covered. Structural design considerations addressed in Chapter 3 include the use of panels as shear wall components.

Emphasis is placed on wall panels with an integral exposed aggregate concrete surface finish. Smooth wall panels and panels with a textured or shaped architectural surface finish are included. Panels having natural stone veneer or ceramic veneer finishes are not covered in detail.

1.3—Responsibility

1.3.1 *General*—Contractual agreements should assign responsibilities to avoid disagreements on basic definitions and decisions originating from the specifying agency. A special report of an ad hoc committee for the responsibility for design of precast concrete structures was published by the Precast/Prestressed Concrete Institute (PCI 1988) and recommends assignment of authority and responsibility for design and construction of precast concrete structures.

This guide covers the design of panels by an engineer/architect. ACI Committee 533 presents supplemental design guidelines that are special to precast concrete wall panels and should be used with ACI 318-08. ACI 318-08 provides minimum design requirements and is legally binding when adopted by the local authority.

Overlapping responsibilities for the structural design of wall panels may introduce conflicts between the engineer/architect and general contractor regarding contract document review, design for handling, installation stresses, in-place loads, and adequacy of connections. It is essential that work assignments and responsibilities be clearly defined in the contractual arrangements.

1.3.2 *Structural design*—The engineer/architect can benefit from preconstruction contact with panel producers. Handling and installation procedures vary widely, and guidelines for these operations should correspond with local practices but be consistent with Chapter 3 of this guide. Most precasters maintain an engineering staff to prepare contract documents and the engineer/architect should interact with this group to obtain constructive advice and suggestions concerning local practice, fabrication details, and fabrication capabilities. When possible, this discussion should take place during the initial design phases of a construction project. Once a job is released for bidding and the structural concepts have been established, changes may be difficult to implement.

1.3.3 *Reinforcement for handling and installation*—Generally, the engineer/architect relies on the manufacturer for developing handling techniques and providing any additional reinforcement required for withstanding handling or installation stresses. The engineer/architect may wish to review calculations for handling stresses.

Contract documents may require the manufacturer to accept responsibility for design of panels to resist the loads shown and to resist other loads that occur during stripping, handling, shipping, and installation. In this case, it is common for contract documents to require that design calculations and installation drawings provided by the panel manufacturer be signed by a professional engineer who is either retained or employed by the manufacturer. When the load information in the contract documents is insufficient, the manufacturer should ask for additional information from the engineer of record.

1.3.4 *Adequacy of connections*—Contract drawings prepared by the engineer/architect should show the connections required and the load support points in sufficient detail to permit construction. During the preparation of shop drawings, manufacturers should be given the opportunity to redesign the connections if redesign will achieve economical details that facilitate manufacture or installation. If connections are designed by the engineer/architect, the manufacturer should review the connections for structural adequacy and economy. If connections are redesigned or other problems are noted, these should be brought to the attention of the engineer/architect for review. Any deviation from or discrepancy in the approved installation drawings should be communicated to the general contractor by the installation contractor before installation. The general contractor should make all necessary arrangements for corrections to be made by the parties involved before installation.

1.3.5 *Handling and installation responsibilities*—Responsibility for panel installation and cleaning, joint treatment, and supply of hardware for handling, attachment, and bracing should be clearly defined in contract documents. The specifier should not prescribe specific subcontractors in the document specifications. General contractors are generally more knowledgeable of the skills and experience of subcontractors who can perform the services and can more easily evaluate the alternatives.

1.3.5.1 *Cleaning*—Specifications should require clean panels after installation and cleaning need not be the object of a separate operation. The precast manufacturer, carrier, or both, are responsible for delivering clean panels (refer to Section 7.6). After panel installation, protecting panels from soiling and staining during subsequent operations should be the responsibility of the general contractor.

1.3.5.2 *Furnishing attachment and handling hardware*—Clip angles, inserts, bolts, and miscellaneous metal items are required for construction with precast panels. These items may be attached to the building frame, embedded in the precast panel for erector or for other trades, or provided loose at the job site for connection purposes.

Responsibility for supplying items to be attached to or placed in the structure to receive precast concrete units depends on structure type and local practice. Contractual agreements should indicate who is responsible for the supply and installation of hardware. When the supporting frame is structural steel, installation hardware is normally supplied and installed by the precast erector or steel fabricator. When the building frame consists of cast-in-place concrete, hardware is normally supplied by the precast manufacturer and placed by the concrete contractor. Detailed hardware layout is prepared by the precast manufacturer for approval by the engineer/architect. Occasionally certain special inserts or sleeves are required for other trades. In these instances, the trade involved is responsible for having such parts approved and delivered to the panel manufacturer in time for embedment in the wall panels. These should be accompanied by the engineer/architect's approved placement drawings and instructions for installation.

1.3.5.3 *Execution of connections*—The general contractor is responsible for accurately constructing bearing surfaces and anchorages for precast elements. When a panel cannot be erected within tolerances specified in the contract documents, the matter should be called to the engineer/architect's attention for consideration and correction.

Changes, other than adjustments within the prescribed tolerances, can only be made after approval. Any adjustments affecting structural performance should be approved by the engineer of record. No panel should be left in an unsafe support condition.

1.3.6 *Shop drawing approval*—Installation and shape drawings prepared by the precast manufacturer (refer to Section 6.1) should be forwarded to the general contractor for approval regarding constructibility and then forwarded to the engineer/architect who checks for conformance with the design requirements and contract documents. Drawings reviewed by the engineer/architect should be returned to the manufacturer with a statement similar to one of the following:

- Reviewed for conformance with the contract documents. No resubmissions necessary.
- Reviewed, as noted, for conformance with the contract documents. No resubmissions necessary.
- Revise and resubmit.
- Rejected.

1.4—Aesthetic considerations

Fabrication techniques and procedures covered in this guide allow flexibility during fabrication to achieve uniform aesthetic results and concrete quality. Performance specifications for the appearance of precast wall panels explaining aesthetic requirements or establishing understandable criteria for acceptance are difficult to achieve. It is recommended that reference samples be used in determining product characteristics and quality, rather than writing restrictions that are difficult to achieve and may prohibit the manufacturer from using a process that offers the best possibility of producing the desired panel.

1.4.1 *Design reference samples*—Full-size sample panels are preferred, but construction specifications may require that the color and texture match small samples. Such samples should be at least 12 x 12 in. (305 x 305 mm), although larger samples may be desirable. If both panel faces are to be exposed, samples should show the finished interior surface as well as the exterior face of the precast.

The manufacturer should submit samples to the general contractor for approval by the engineer/architect, while retaining duplicate samples. If the sample is not approved, resubmissions should be made until approval is obtained. Sample approval should be in writing with reference to the correct sample code number, or the approval may be written on the sample itself.

1.4.2 *Range samples*—At least three full-scale (but not necessarily full-size) sample panels should be specified. These sample panels should contain typical cast-in inserts, reinforcing steel, and plates as required for the project. These panels should establish the range of acceptability with respect to color and texture variations, surface defects, and overall appearance. It should be clearly stated in the contract documents how long the full-scale samples should be kept at the point of manufacture (precasting plant) or at the job site for comparison. Approved full-scale panels should be allowed to be used in the completed structure. If full-scale samples are required before, or at the beginning of, fabrication, lead time is necessary and the construction schedule should be adjusted accordingly. When full-scale sample panels are not specified, the first fabrication panels should be submitted for inspection and approval by the engineer/architect.

CHAPTER 2—NOTATION AND DEFINITIONS

2.1—Notation

b = width of cross section
f_c' = concrete compressive strength specified at age considered during design
h_{eff} = effective thickness of member
I_g = moment of inertia of gross concrete section neglecting reinforcement
k = effective length factor
ℓ = length of span
r = radius of gyration of cross section
ℓ_u = unsupported length of panel

2.2—Definitions

ACI provides a comprehensive list of definitions through an online resource, "ACI Concrete Terminology," (http://terminology.concrete.org). Definitions provided herein complement that resource.

bowing—the deviation of the edge or surface of a planer wall member, in the out-of-plane direction, from a line passing through any two corners of the member

camber—a deflection that is intentionally built into a structural element or form to improve appearance or to nullify the deflection of the element under the effects of loads, shrinkage, and creep.

surface out-of-planeness (roughness)—a local smoothness variation rather than a bowing variation. The tolerance for this variation is usually expressed in fractions of an inch (millimeter) or in inches per 10 ft (millimeters per 3 m). Although other criteria are available, the tolerance is typically checked with a 10 ft (3 m) straightedge or equivalent and definition of roughness.

tolerance—a permitted variation from the basic dimension or quantity as in the length, width, or depth of a member.

unequal bowing—may be observable when panels are viewed together on the completed structure. When two panels bow in the same direction, the magnitude of unequal bowing is determined by subtracting one bowing value from another. When panels bow in opposite directions, the convex bowing is taken as positive (+) and concave bowing is taken as negative (–) by a standard sign convention, the unequal bowing is the algebraic difference.

warping—deviation of a planer surface due to displacement of one corner in relation to any two adjacent corners. Warping tolerances are stated in terms of the magnitude of the corner variation. This value is usually given in terms of the allowable variation per 1 ft (300 mm) of distance from the nearest adjacent corner with a not-to-exceed maximum value of comer warping.

CHAPTER 3—WALL PANEL DESIGN

3.1—Introduction

This guide presents design recommendations for prestressed and conventionally reinforced concrete wall panels. Load-bearing and non-load-bearing panels are covered. Precast wall panels can be differentiated on the basis of structural function as well as panel configuration. The classes and types of panels covered in this guide are defined in the following.

3.1.1 *Panel classes*

3.1.1.1 *Non-load-bearing panel (cladding)*—A precast wall panel that transfers negligible load from other elements of the structure. This panel is generally designed as a closure panel and should resist all applicable service and factored loads from wind forces, earthquake-induced forces, thermally-induced forces, forces from time-dependent deformations, self-weight, and those forces resulting from handling, storage, transportation, and installation.

3.1.1.2 *Load-bearing panel*—A precast wall panel designed to carry loads from one structural element to other structural elements. Load-bearing panels should interact with other panels and the supporting structural frame to resist all applicable design loads in addition to those listed for non-load-bearing panels. Load-bearing panels also include panels designed to function as shear walls.

3.1.2 *Panel types*

3.1.2.1 *Solid panel*—A panel of constant thickness; an allowance for surface texture should be made in determining effective thickness.

3.1.2.2 *Hollow-core panel*—Precast panel that has voids within the thickness in one direction for the full length of the panel.

3.1.2.3 *Sandwich panel*—Precast panel consisting of two layers of concrete separated by a nonstructural insulating core.

3.1.2.4 *Ribbed panel*—Precast panel consisting of a slab reinforced by a system of ribs in one or two directions.

3.2—Design guidelines

3.2.1 *General*—Precast wall panels should be designed according to ACI 318-08 except as modified in Sections 3.2.3, 3.2.4.2, 3.2.5, 3.3, 3.4.2, 3.5.2, and 3.5.3 of this guide. ACI 318-08 requirements may be legally binding.

3.2.2 *Forces for design*—Where applicable, precast wall panels should be designed to resist the following forces due to:

- Construction, handling, storage, and transportation.
- Installation and impact.
- Gravity dead and live loads and lateral loads from soil.
- Hydrostatic pressure, wind, and seismic action.

Precast panels should also be designed to resist the forces developed by the following:

- Differential support settlement.
- Deformations from creep and shrinkage.
- Structural restraint.
- Effects of environmental temperatures.
- Thermal movement or bowing.
- Volume change of the panel with respect to the supporting structure.
- Local stress concentrations in the vicinity of connections and applied loads.

3.2.3 *ACI 318-08 provisions applicable for member design*—The following chapters or sections of ACI 318-08 should be followed for the design aspects enumerated, except as otherwise modified in this guide.

Effective prestress—Section 18.6. The average concrete stress due to prestressing after losses is limited to a range of 150 to 800 psi (1.0 to 5.5 MPa).

Flexure—Chapter 10 for nonprestressed panels and Chapter 18 for prestressed panels. Requirements of Section 10.7 for deep beams apply regardless of whether the member is prestressed or nonprestressed.

Shear—Chapter 11 for both prestressed and nonprestressed panels.

Bearing—Sections 10.14 and 15.8.

Combined bending and axial load—Section 10.3.

3.2.4 *Combined bending and axial load*

3.2.4.1 *General*—All forces listed in Section 3.2.2 should be considered in designing wall panels for combined bending and axial load. Also, the effects of secondary forces caused by deflection, variable moment of inertia, stiffness, and duration of load should be considered. Axial forces, bending moments, and shear forces should be determined from an analysis of the structure. Considerations of member translation, joint translation, or both, should be considered in the analysis. In place of the aforementioned procedure, compression member design may be based on the approximate procedures given in Section 3.2.4.2.

3.2.4.2 *Approximate evaluation of slenderness effect*—Procedures described in Section 10.10 of ACI 318-08 should be followed for determining the unsupported length, effective length, and radius of gyration of precast wall panels.

(a) Slenderness effects may be neglected if slenderness conforms to Section 10.10.4.1 or 10.10.4.2 of ACI 318-08. For compression members with slenderness $k\ell_u/r$ greater than 150, an analysis according to Section 3.2.4.1 of this guide should be made.

(b) The magnified moment for design of a compression member should be determined according to Section 10.10.5.1 of ACI 318-08.

(c) For precast wall panels considered to be reinforced concrete compression members by these recommendations, the provisions of Section 10.10.5.2 of ACI 318-08 can be used instead of a more accurate analysis.

(d) For precast wall panels considered to be prestressed concrete compression members by these recommendations, the provisions of Section 5.9 of the *PCI Design Handbook* (MNL-120-10) can be used instead of a more accurate analysis.

(e) An equivalent uniform bending moment factor, defined in accordance with Section 10.10 of ACI 318-08 should be considered for precast wall panels braced against sidesway and without transverse load between supports.

(f) The minimum eccentricity, according to Sections 10.3.6 and 10.3.7 of ACI 318-08, as appropriate, should be considered for precast wall panels when no bending moment occurs at either end of the panel.

3.2.5 *Reinforcement*—Precast wall panels are not required to have lateral hoop or spiral reinforcement unless analysis indicates this reinforcement is required.

Limits of reinforcement for precast wall panels should conform to Sections 7.10, 7.12, 10.9, 14.3, and 18.8 of ACI 318-08. Two-way reinforcement is not required for some essentially one-way panels, such as hollow-core panels.

3.3—Effective dimensions

3.3.1 *Effective thickness*

3.3.1.1 *General*—The effective panel thickness for design may be different from the total panel thickness. The following sections explain how to determine the effective thickness for design purposes and Fig. 3.3.1.1(a) through 3.3.1.1(c) provide the general characteristics of the various effective thicknesses.

3.3.1.2 *Architectural faced panels*—The effective thickness of a wall panel with an integral exposed aggregate surface should be determined by subtracting the depth of aggregate reveal from the total panel thickness if the depth of aggregate reveal exceeds 3 percent of the total thickness. The effective thickness of a wall panel with a noncomposite facing should not include the separate facing thickness.

3.3.1.3 *Solid, hollow-core, and ribbed panels*—Effective panel thickness should be determined by Eq. (3.3.1.3).

$$h_{eff} = \sqrt[3]{\frac{12I_g}{b}} \qquad (3.3.1.3)$$

where I_g is the uncracked moment of inertia accounting for voids or ribs, if they exist.

3.3.1.4 *Sandwich panels*—Effective thickness of a sandwich panel may be assumed equivalent to the effective thickness of the two wythes plus insulation only if mechanical shear connectors capable of developing full composite action are used to connect the interior and exterior wythes. In such cases, the effective thickness may be determined from Eq. (3.3.1.3).

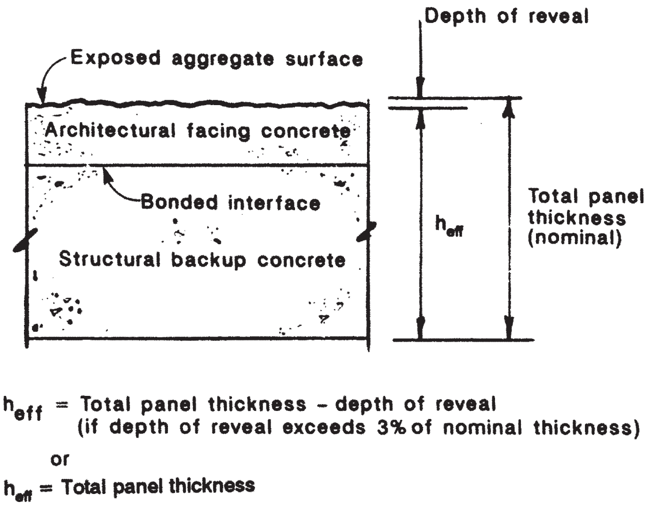


Fig. 3.3.1.1(a)— Effective thickness of architectural faced panels.

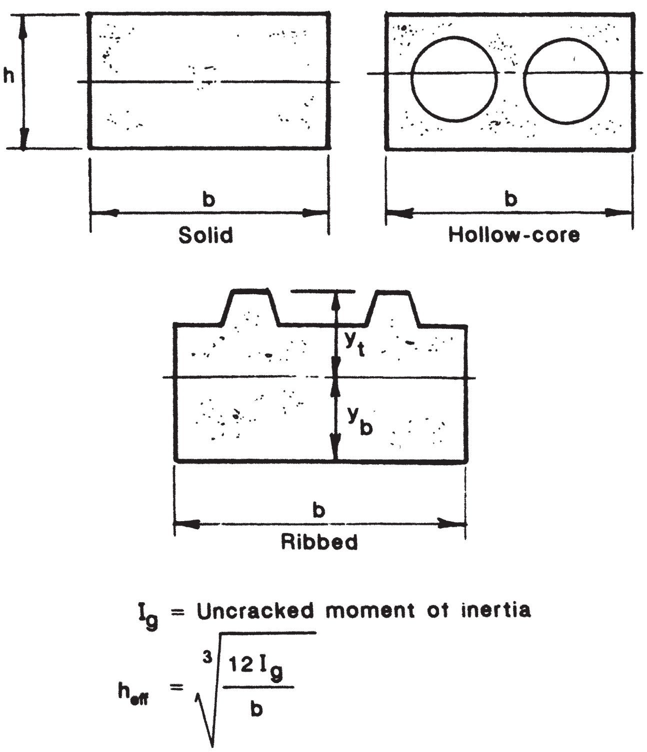


Fig. 3.3.1.1(b)—Effective thickness of solid, hollow-core, or ribbed panels.

If the insulation core is cellular lightweight concrete or lightweight concrete made with mineral aggregates, the shear transfer through the insulation core should not exceed the shear allowed by the strength of the insulating concrete core.

When only partial composite action between wythes exists, and loadings are from lateral forces or long-term sustained loads, the two wythes should be considered as separate members unless testing is conducted to verify panel behavior. Refer to Section 3.4.2 for limitations on the maximum slenderness ratio of the load-bearing wythe.

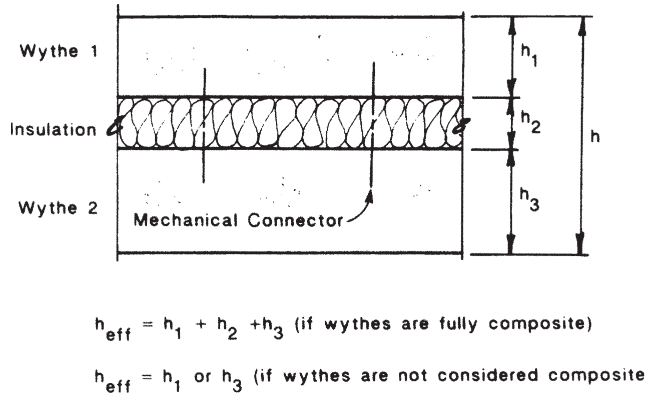


Fig. 3.3.1.1(c)—Effective thickness of sandwich panels.

3.3.1.5 *Panels of irregular shape*—Panels not conforming to the configurations listed in this section may have the effective thickness determined by analysis or testing based on cracking moment.

3.3.2 *Effective width*—When concentrated loads or bending moments are applied to the top and bottom of a wall panel, the effect of local stress near the applied concentrated load or bending moment should be investigated. The effective width for a concentrated load may not exceed the center-to-center distance between supports, or the width of the loaded portion plus six times the wall panel effective thickness on each side of the concentrated load. The effective width for concentrated bending moments may not exceed the effective thickness of the wall panel or corbel width at the point of concentrated bending moment, whichever is greater, plus three times the effective wall panel thickness each side of the concentrated bending moment. Effective width may also be determined by a more accurate analysis.

3.4—Limiting dimensions

3.4.1 *General*—Limiting dimensions for precast wall panels should be based on requirements of concrete placement, protection of prestressed and nonprestressed reinforcement, fire resistance, member and local stability, deflection, handling, transportation, and concrete cracking.

3.4.2 *Distance between supports*—Spacing of lateral supports for a precast wall panel loaded in flexure only should not exceed 50 times the effective width of the compression flange or face. The maximum slenderness $k\ell_u/r$ of a precast wall panel should not exceed 200. Spacing between lateral supports of a precast panel carrying axial load and bending moment should not exceed 50 times the effective width of the compression face or flange for stemmed sections. Lateral bracing should be attached to the compression region of the member cross section needing lateral support unless it can be shown that other portions of the cross section have sufficient stiffness to brace the member.

3.5—Serviceability

3.5.1 *General*—The action of service loads on deflections perpendicular and parallel to the wall panel should be considered. Fatigue, impact, cracking, and in-plane lateral

Table 3.5.2—Deflection limits for precast wall panels

Member type	Deflection to be considered	Deflection limitation
Load-bearing precast wall panels	Immediate deflection due to combined effects of prestress (if any), self-weight, and superimposed dead load.	ℓ/240 but not greater than 3/4 in. (20 mm)
	Immediate deflection due to live load, in. (mm).	ℓ/360 but not greater than 3/4 in. (20 mm)
Non-load-bearing precast wall panel elements likely to be damaged by large deflection	That part of the total deflection after the installation of the non-load-bearing element (sum of long-time deflection due to all sustained loads and the immediate deflection due to live load).	ℓ/480 but not greater than 3/4 in. (20 mm)

stability at service load conditions should be accounted for in design.

3.5.2 *Computed permissible deflections*—Precast wall panel dimensions should be chosen so that under service load conditions, deflection of any point on the panel measured from its original position should not exceed the limits given in Table 3.5.2. In calculating deflection, nonlinear behavior of the materials, structural member, or both, should be recognized.

3.5.3 *Cracking*

3.5.3.1 *Acceptability of cracking*—Precast wall panels typically undergo less cracking than cast-in-place concrete, but they are not generally crack-free. Computations based on current engineering practice assume that cracks will occur in a concrete member even though they may not be visible to the naked eye. It is the control and acceptability of these cracks that should be evaluated. Wall panels containing cracks up to 0.012 in. (0.30 mm) wide should be acceptable. Crack size limitations are specified for structural reasons. Additional guidance on cracking and its causes can be found in the PCI MNL-116-99, PCI MNL-117-96, PCI MNL-120-10, PCI MNL-122-07, ACI 224.1R-07, and ACI 224R-01.

Aesthetic crack size limitation depends on surface texture and required appearance. On coarse textured surfaces, such as exposed aggregate concrete, and on smooth surfaces comparable to the best cast-in-place structural concrete, the structural limitation would be aesthetically acceptable. Note also that cracks will become more pronounced on surfaces receiving a sandblasted or acid-etched finish.

Cracks in precast concrete panels may be classified as hairline, cleavage, or fracture cracks.

- Hairline cracks are surface cracks of minute width, visible but not measurable without magnification.
- Cleavage cracks are cracks not over 0.012 in. (0.30 mm) wide that, in the judgment of the inspector, penetrate at least to the plane of the nearest reinforcing steel.
- Fractures are total cleavages of measurable width through which water may pass freely.

Crazing consists of hairline cracks in an approximate hexagonal or octagonal pattern on the concrete surface. These can occur in many panels, but they are not readily visible in exposed aggregate surfaces or when the concrete is dark. They are most apparent on white panels, flat surfaces, and smooth finishes. Crazing is of little structural importance and should not be cause for rejection. If panels are to be installed in an environment that may be the source of considerable soiling, it may be advisable to avoid smooth concrete finishes to render potential crazing less visible.

3.5.3.2 *Crack prevention and control*—Significant reductions in crack widths can be obtained by proper selection and location of reinforcement. Maintaining accurate steel positioning during the casting operation also aids in reducing crack widths. Reinforcement is most effective when it consists of more closely-spaced, smaller-diameter bars or wire, particularly in thin sections. Welded wire fabric reinforcement is commonly used instead of reinforcing bars because of the relatively close wire spacing (4 to 6 in. [100 to 150 mm] or less).

Flexural reinforcement distribution requirements in Section 10.6 of ACI 318-08 should be followed for reinforced precast or architectural wall panel surfaces not exposed to view. When the geometry of the precast member is more like that of a two-way slab, flexural reinforcement requirements of Section 10.6 of ACI 318-08, may lead to crack widths wider than expected. For information on crack repair, refer to ACI 224.1R-07.

3.5.3.3 *Limit on flexural tension*—For conventionally reinforced and prestressed wall panels where the exposed surface is to remain free of discernible cracks, the maximum flexural tension in the member under loads produced by stripping, handling, transportation, impact, and live load effects should be less than $5\sqrt{f_c'}$. The tensile strength value of concrete should be modified according to Section 11.2 of ACI 318-08 if lightweight aggregate concrete is used.

3.6—Connections

3.6.1 *General*—Wall panel units should be safely and adequately seated and anchored by mechanical means capable of sustaining all loads and stresses that may be applied to the wall panel, including positive or negative wind pressures and seismic forces where required by ACI 318-08. Whenever possible, panels should be concentrically supported to avoid bowing and warping due to stress differential between inside and outside faces of the panel.

When the wall panel is designed to serve as a structural member, it may be required to carry imposed vertical loads, resist bending and shear (other than that caused by its own weight and volumetric changes), or it may be designed to function as a shear wall. When wall panels are designed to transmit load from one to another, consideration should be given to the additional loads required for design of the connection(s). Concepts for design of connections for precast wall panels may be found in PCI MNL-117-96 and PCI MNL-123-88.

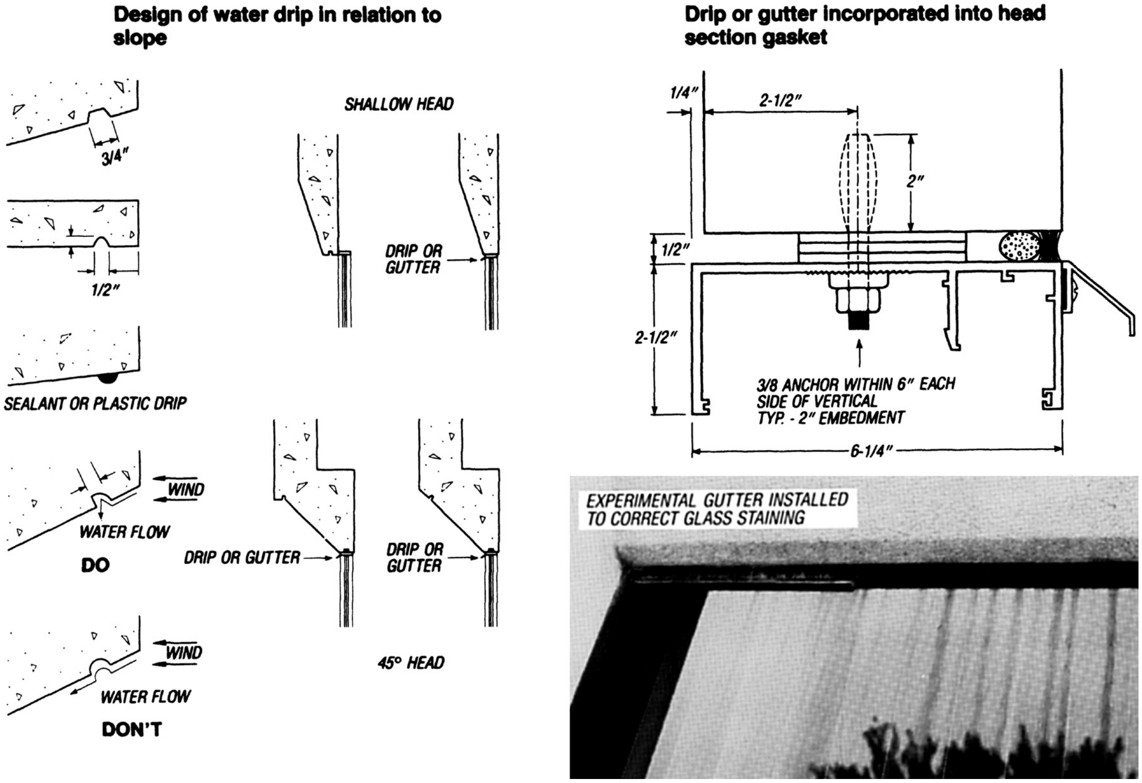


Fig. 3.7.1—Design of water drip in relation to slope.

3.6.2 *Panel movement*—Wall panel connection assemblies should be designed to allow for panel movement induced by temperature or caused by volumetric change in the concrete, moisture differential, creep in prestressed panels, and differential movement or drift between building frame and wall panel units. Design guidance design for these conditions can be found in PCI MNL-120-10 and Gaylord et al. (1996).

3.6.3 *Bearing seats*—Because of the indeterminacy in the analysis of load-transfer connection assemblies, bearing seats should be provided for panels weighing more than 5000 lb (2268 kg). These connections are typically corrosion protected and behind a weather proof joint; hence, maintenance is not required.

The designer should avoid hanging panels from inserts, anchors, or other connection devices in direct tension near the top edge of the panel. Clips, clamps, welding plates, and brackets are commonly used to resist horizontal and lateral loads. When they are intended to transfer the panel weight to the structure, rigorous analysis is required in their design, and special precautions should be enforced to ensure proper installation.

3.6.4 *Haunches*—Concrete haunches used to positively seat panels should conform to shear requirements of Section 11.9 of ACI 318-08 and should be designed for eccentric loading and combined shear, bending, tension, and bearing stresses. The effect of eccentricity, which causes panel deflection, should be considered in the design of panel reinforcement.

3.6.5 *Panel inserts*—The design of wall panel inserts that are part of a connection assembly should be based on the load factors and strength reduction factors (ϕ factors) specified in Sections D.4.4 and D.4.5 of ACI 318-08. Connections should not be the weak link in a precast system. Inserts should have a safety factor consistent with the insert manufacturer's recommendation.

3.6.6 *Fire resistance*—Wall panel connections should be fireproofed to have minimum fire resistance equivalent to that required by local code for the wall panels.

3.6.7 *Weld design*—Potential relative movement between the panel and supporting structural frame or adjacent panels should be investigated when designing welds. The effects of possible concrete cracking due to welding heat on the precast panel or its supporting concrete frame should be considered in the design of the connection assembly.

3.7—Architectural features

3.7.1 *Drip details*—Directed slow-water runoff of rainwater over building facades and dirt accumulation can contribute to staining or etching of glass surfaces. This phenomenon is fully explained in PCI MNL-122-07. Appropriate building details can reduce the water discharged to the glass. Concrete frames at window heads should, wherever possible, be designed so that they do not splay down and back toward the glass unless drip details are incorporated into the frames. Without drip details, a direct, slow wash down of the glass should be anticipated.

The drip section should be designed in relation to the slope of the concrete surface (Fig. 3.7.1). To avoid a weakened section that is likely to chip, the drip should not be located too close to the edge of the precast unit. Using edge drips and a second drip or gutter serves as a dual line of defense against slow water runoff. This can be accomplished by having a cast-in drip in the panel or by using of aluminum or neoprene extrusions across the window head, which have either an integral gutter or an extended drip lip of at least 1 in. (25 mm) (Fig. 3.7.1).

3.7.2 *Joint size and location*—Joints between precast panels or panels and adjacent building materials should be wide enough to accommodate anticipated panel and building movements. No joint should ever be designed to be less than 3/8 x 3/8 in. (10 x 10 mm). Particular care should be given to joint tolerances so the joint sealant system performs within its design capacities. For optimum performance and maximum sealant life, recommendations of the sealant manufacturer should be followed.

Panels less than 15 ft (4.6 m) long may have 1/2 in. (13 mm) joints, but all other panels should have at least 3/4 in. (19 mm) joints. Corner joints should be at least 1/4 in. (6 mm) to accommodate extra movement and bowing that occurs there. Joint widths less than or equal to 3/8 in. (10 mm) are not recommended for any sealant installation. When joints are too narrow, adjacent panels or building materials may contact each other and be subjected to induced loading, distortion, cracking, and crushing of ends.

CHAPTER 4—TOLERANCES

4.1—General

Precast structures should be designed and detailed so that the complete structure will be safe, functional, aesthetically appealing, and economical. No structure is exactly level, plumb, and straight, so all construction and materials should be specified with tolerances limiting deviation from design values. These tolerances require monitoring to construct the structure as designed. General construction tolerances for cast-in-place and precast concrete have been summarized in ACI 117-10, ITG-7-09, and PCI MNL-135-11. This chapter presents tolerances specifically applicable to precast concrete wall panels. Three tolerance groups should be established as part of precast concrete wall panel design. Wall panels and their component details should conform to:

- Product tolerances (Section 4.4).
- Installation tolerances (Section 4.6).
- Interfacing tolerances (Section 4.7).

When tolerances are understood and provided for in the design stage, determining and specifying them is easier. The precaster, constructor, and erector should understand these allowances to construct the structure as designed.

4.2—Reasons for tolerances

Tolerances are needed for product, installation, and interfacing for the following reasons:

- *Structural considerations*—to ensure structural design accounts for factors sensitive to variations in dimensional control. Examples include eccentric loading, bearing areas, hardware and hardware anchorage locations, and locations of reinforcing or prestressing steel.
- *Performance*—to ensure acceptable performance of joints and interfacing materials in the finished structure.
- *Appearance*—to ensure that deviation from theoretical requirements will be controllable and result in acceptable appearance. Large deviations are objectionable, whether they occur in an isolated manner or cumulatively.
- *Cost*—to ensure ease and speed of fabrication and installation by having a known degree of accuracy in the dimensions of the precast members.
- *Legal considerations*—to avoid encroaching on building lines.
- *Contractual*—to establish a known acceptability range and to establish responsibility for developing, achieving, and maintaining mutually agreed-on tolerance values.

4.3—Role of engineer/architect

The engineer/architect should coordinate the tolerances for precast work with the requirements of other trades whose work relies on or is adjacent to the precast. Tolerances should be reasonable, realistic, and within generally accepted limits, because fabrication and installation costs are directly related to degree of precision required. Thus, it is economically desirable and practically safer to design with maximum flexibility and to maintain liberal tolerance requirements. Tolerances in this guide are basic guidelines only. The engineer/architect determines whether a deviation from the allowable tolerances affects safety, appearance, or other trades.

When design involves features sensitive to the cumulative effect of tolerances on individual portions, the engineer/architect should anticipate and provide for this effect by setting a cumulative tolerance limit or by providing escape areas where accumulated tolerances or fabrication errors can be absorbed. All tolerance consequences for a particular design should be investigated to determine whether a change is necessary in the design or in the tolerance level for the design. There should be no possibility of minus tolerances accumulating so that the bearing length of members is reduced below the required design minimum. In this case, the engineer/architect should specify minimum bearing dimensions.

Careful inspection of listed tolerances reveals that many times one tolerance overrides another. The permitted variation for one element of the structure should not require another element of the structure to exceed its tolerances. The precaster and general contractor should review restrictive tolerances to determine compatibility with other elements and that the tolerances can be met. For example, a requirement stating "no bowing, warping, or movement is permitted" is impractical. All involved in the design and construction process should understand that tolerances herein are for guidance on the range of acceptability and not an automatic standard for rejection. If these tolerances are exceeded, the engineer/architect may accept the product if it meets any of the following criteria:

(a) Exceeding the tolerance does not affect structural integrity, architectural performance, or serviceability requirements of the member.

(b) Member can be brought within tolerance by structurally and architecturally satisfactory means.

(c) Total erected assembly can be modified to meet all structural and architectural requirements.

4.4—Product tolerances for wall panels

4.4.1 *General*—Product tolerances cover the dimensions and dimensional relationships of individual precast concrete members. All tolerances should be based on a practical degree of accuracy, which is achievable while satisfying functional and appearance requirements and preventing costs from becoming prohibitive. This requires consideration of the amount of repetition, the size, and other characteristics of the precast member.

Fabrication tolerances are standardized throughout the precast industry and for economic reasons should be made more demanding only where absolutely necessary. For example, bowing or warping tolerances for flat concrete panel members with a honed or polished finish might have to be decreased to 50% of typical tolerances to avoid joint shadows. When design details lead to an alignment problem or provide inadequate joint size, product tolerance may need adjustment to compensate for joint design problems. In establishing casting tolerances for panels, the following items should be considered:

- Length or width dimensions and straightness of the precast element will affect the joint dimension, dimensions of openings between panels, and perhaps the overall structure length.
- Out-of-square panels can cause tapered joints and make adjustment of adjacent panels extremely difficult. Sealant application difficulties due to tapered joints can lead to water leakage problems.
- Thickness variation of the precast unit becomes critical when interior surfaces are exposed to view. A nonuniform thickness of adjacent panels will cause offsets at the front or rear faces of the panels.

4.4.2 *Dimensional tolerances*—Architectural precast concrete panels should be manufactured and installed so that each panel face exposed to view after installation complies with the dimensional requirements shown in ITG-7-09. Tables 2.1 and 4.1 in ITG-7-09 also list the position tolerance for cast-in items within the panel. These are for typical generic panels, and the tolerances may require adjustment for specific job conditions. Cast-in grooves, reglets, or lugs that are to receive glazing gaskets should be held close to their correct location. Gasket manufacturers place restrictive tolerances on groove width and surface smoothness necessary to obtain a proper moisture seal of the gasket. Misalignment of reglets at corners, or casting them in a warped or racked position restricts proper installation of the glazing gasket.

Dimension tolerances for standard precast ribbed panels and hollow-core slabs used as wall panels are shown in Table 2.1 of ITG-7-09. Standardized ribbed and hollow-core members, typically used for roof and floor units, are also frequently used as wall panels. Tolerances for these standardized structural units are generally more liberal than those for architectural panels. If the engineer/architect cannot accept the standard structural tolerances of ribbed and hollow-core units when using them as wall panels, they should specify the architectural tolerances as given in Table 4.1 of ITG-7-09 or other tolerances as required.

4.4.3 *Warping and bowing*—Warping and bowing are defined in Section 2.2 and illustrated in Fig. 1.2 and 1.5 of ITG-7-09. Nonsymmetrical placement of reinforcement may allow warping due to lack of restraint of drying shrinkage and thermal movements. Note that surface out-of-planeness (also defined in Section 2.2) is differentiated from bowing because it is not a characteristic of the entire panel shape, but a local smoothness variation. Tolerance for local smoothness is checked with a straightedge or the equivalent as shown in Fig. 1.4 of ITG-7-09 and the measurement of warping in Fig. 1.5 of ITG-7-09.

Table 4.4.3 shows a relationship between overall flat panel dimensions and cross-sectional thickness. If the thickness is less than suggested in Table 4.4.3, warping tolerances should be reviewed for the possibility of increasing the tolerance. Panels thinner than those in Table 4.4.3, ribbed panels, and panels manufactured using aggregates larger than 3/4 in. (19 mm) exposed at the surface need further consideration when establishing bowing and warping tolerances. Tolerances for flat panels of nonhomogeneous materials, such as two widely different concrete mixtures or natural stone veneer with concrete backup, should be reviewed as they may have to be increased or reduced to meet design criteria.

4.5—Installation tolerances for wall panels

4.5.1 *Discussion*—Installation tolerances are required for the functional matching of the precast elements with the building structure. The engineer/architect should set tolerances that are compatible with the desired architectural expression and detailed to the building structure and site conditions. Installation tolerances should be set to achieve uniform joint and plane wall conditions considering the individual element design, shape, thickness, composition of materials, and overall scale of the element in relation to the building. Installation tolerances affect the work of several trades and should be consistent with the tolerances specified for those trades. It is the responsibility of the engineer/architect to ensure that tolerances are compatible.

The engineer/architect should review proposed installation tolerances with the panel manufacturer and the erector before installation commences. Proposed changes by the manufacturer or erector from the original plan should be stated in writing and noted on installation drawings. Agreement should be reached before scheduling equipment for panel installation.

The general contractor, in consultation with the precast concrete installation contractor, should check dimensions and location of the in-place structure before placing precast panels. Any dimensional discrepancies that may affect installation should be reviewed and resolved with the engineer/architect before starting installation. The contractor may have to make corrections to the interfacing structure.

Location or installation tolerances for wall panels should be noncumulative. Recommended tolerances are listed in

Table 4.4.3—Guidelines for panel thicknesses for overall panel stiffness consistent with suggested normal panel bowing and warping tolerances

Panel dimensions	8 ft (2.44 m)	10 ft (3 m)	12 ft (3.66 m)	16 ft (4.88 m)	20 ft (6.10 m)	24 ft (7.32 m)	28 ft (8.53 m)	32 ft (9.75 m)
4 ft (1.22 m)	3 in. (76.2 mm)	4 in. (102 mm)	4 in. (102 mm)	5 in. (127 mm)	5 in. (127 mm)	6 in. (152 mm)	6 in. 152 mm)	7 in. (178 mm)
6 ft (1.83 m)	3 in. (76.2 mm)	4 in. (102 mm)	4 in. (102 mm)	5 in. (127 mm)	6 in. (152 mm)	6 in. (152 mm)	6 in. (152 mm)	7 in. (178 mm)
8 ft. (2.44 m)	4 in. (102 mm)	5 in. (127 mm)	5 in. (127 mm)	6 in. (152 mm)	6 in. (152 mm)	7 in. (178 mm)	7 in. (178 mm)	8 in. (203 mm)
10 ft (3 m)	5 in. (127 mm)	5 in. (127 mm)	6 in. (152 mm)	6 in. (152 mm)	7 in. (178 mm)	7 in. (178 mm)	8 in. (203 mm)	8 in. (203 mm)

Table 5.1 of ITG-7-09, which shows installation tolerances for nonstructural architectural wall panels, as well as Table 3.1 of ITG-7-09, which shows installation tolerances for structural wall panels.

4.5.2 *Control points and benchmarks*—To ensure accurate application of installation tolerances, the general contractor should establish and maintain accurate control points and benchmarks in areas that will remain undisturbed until final completion and acceptance of a project.

The general contractor should provide the erector with a building perimeter offset line at each floor approximately 2 ft (0.6 m) from the edge of the floor slab and benchmarks on all perimeter columns. Offset lines and benchmarks should be maintained until final completion and acceptance of the work. They may be scored into columns and floor slabs or set as chalk lines and lacquered for protection.

4.5.3 *Joint problems*—Width variations between adjacent joints can be minimized by setting out joint centerlines equally spaced along an elevation and centering panels between them. The larger the panels, the wider the joint should be to accommodate realistic tolerances in straightness of panel edge, slope of edge, and panel width. Alignment for exterior elements should be controlled by assuming that the outside face of the element is critical. Variations from true length or width dimensions of the overall structure are normally accommodated in the joints. Where this is not feasible or desirable, variations should be accommodated at the corner elements, in expansion joints, or in joints adjacent to other wall materials.

Joint widths should be designed as liberally as practicable if variations in overall building dimensions are to be absorbed in the joints. This may be coupled with a closer tolerance for variations from one joint to the next for appearance purposes. Individual joint width tolerance should relate to the number of joints over a given building dimension. For example, to accommodate reasonable variations in actual site dimensions, a 3/4 in. (19 mm) joint may be specified with a tolerance of ±1/4 in. (6 mm) but with only a 3/16 in. (4.5 mm) differential allowed between joint widths on any one floor, or between adjacent floors.

Where a joint has to match an architectural feature such as false joints, a ±1/4 in. (6 mm) variation from the theoretical joint width may not be acceptable and a tighter tolerance specified. Adjustment in building length will then have to be accommodated at the corner panels or in joints adjacent to other wall material.

If reasonable tolerances and adjustments are designed into the construction details and adhered to, the erector should be able to:

- Minimize joint irregularities such as tapered joints (panel edges not parallel).
- Minimize jogs at intersections.
- Minimize non-uniform joint widths.
- Maintain proper opening dimensions.
- Properly construct all precast connections.
- Align vertical faces of the units to avoid offsets.
- Prevent accumulation of tolerances.

More precise installation and general appearance improvements are thus achieved.

4.6—Interfacing considerations

4.6.1 *General*—Interface tolerances and clearances are those required for joining different materials and accommodating the relative movements between such materials during the life of the building. They cover products installed before precast installation and after the precast members are in place. The engineer/architect should provide for proper clearances between the theoretical face of the structure and the back face of the precast element. The face of the structure may be precast concrete, cast-in-place concrete, masonry, or a structural steel frame. Adjacent materials include products such as glass or subframes that are installed after precast panels are in place. Clearance space provides a buffer where installation, product, and interface tolerances can be absorbed.

Where matching of the manufactured materials depends on work at the construction site, interface tolerances should equal installation tolerances. Where execution is independent of site work, tolerances should closely match the standard tolerances of the materials to be joined. Fabrication and installation tolerances of other materials should be considered in design. Precast elements should be coordinated with and accommodate the other structural and functional elements comprising the total structure. Unusual requirements or allowances for interfacing should be stated in the contract documents.

4.6.2 *Building frame tolerances*—Installation tolerances for precast panels are largely determined by the actual alignment and dimensional accuracy of the building founda-

Table 4.6.2—Supplementary tolerances for cast-in-place concrete frames to which precast concrete is to be attached

Footings, caisson caps, and pile caps	
Variation of bearing of surface from specified elevation	±1/2 in. (±13mm)
Piers, columns, and walls	
a. Variation in plan from straight lines parallel to specified linear building lines:	1/40 in./ft (0.7 mm/0.3 m) for adjacent members less than 20 ft (6 m) apart or any wall or bay length less than 20 ft.
	1/2 in. (13 mm) for adjacent members 20 ft (6 m) or more apart or any wall or bay length 20 ft (6 m) or more.
b. Variation in elevation from lines parallel to specified grade lines:	1/40 in./ft (0.7 mm/0.3 m) for adjacent members less than 20 ft (6 m) apart or any wall or bay length less than 20 ft.
	1/2 in. (13 mm) for adjacent members 20 ft (6 m) or more apart or any wall or bay length 20 ft (6 m) or more.
Anchor bolts	
a. Variation from specified location in plan:	3/4 in. (19 mm) and 7/8 in. (22 m) bolts ±1/4 in. (6 mm)
	1 in. (25 mm), 1-1/4 in. (32 mm), and 1-1/2 in. (38 mm) bolts ± 3/8 in. (10 mm)
	1-3/4 in. (44 mm), 2 in. (51 mm), and 2-1/2 in. (64 mm) bolts ±1/2 in. (13 mm)
b. Variation center-to-center of any two bolts with an anchor bolt group:	≤1/8 in. (≤3 mm)
c. Variation from specified elevation:	±1/2 in. (±13 mm)
d. Anchor bolt projection:	–1/4 in., +1/2 in. (–6 mm, +13 mm)
e. Plumbness of anchor bolt projection:	±1/16 in./ft (±1.6 mm/0.3 m)

tion and frame. The general contractor is responsible for the plumbness, levelness, and alignment of the foundation and structural frame, including the location of all bearing surfaces and anchorages for precast products. Controlling foundation and building frame tolerances is of critical importance and these tolerances should be included in the contract documents. To install precast elements plumb, square, and true, the actual location of surfaces affecting the alignment of precast elements should be known before installation. The levels of floor slabs and beams, vertical alignment of floor slab edges, and the plumbness of columns or walls should be considered.

Concrete cast-in-place frames to which precast elements are attached should meet the tolerances in Table 4.6.2 and the requirements of ACI 301-10 and ACI 117-10.

Variations in floor heights are greater and more prevalent in cast-in-place structures than in other structural frames. This affects the alignment of precast insert with the cast-in-place connection device.

Tolerances for cast-in-place structures may have to be increased to reflect local trade practices, structure complexity, and environmental conditions. In Fig. 3.3 of ITG-7-09, installation tolerances for beams and spandrels are shown, specifically precast element to precast element, precast to cast-in-place concrete and masonry, and precast to steel frame.

4.6.3 *Mixed construction*—ACI 117-10 applies only to reinforced concrete and masonry buildings, and AISC 325-05 only to steel building frames. Tolerances in these standards do not apply to buildings of mixed construction, such as concrete floor slabs carried by steel beams or concrete-encased structural steel members. Obviously, the location of the face of the concrete on an encased steel member and the location of the steel member itself are both critical. Because the alignment of mixed construction members and encased members is not controlled by referencing the aforementioned standards, the engineer/architect should require that the location of all such materials contiguous to the precast unit be controlled within stated limits. One recommendation is that tolerances be no more than those specified in ACI 301-10 for reinforced concrete buildings. When there is doubt as to the level of mixed construction tolerances, the precast concrete manufacturer may be consulted for advice.

4.6.4 *Steel building frames*—Precast concrete panels should be erected as uniformly as possible around the entire perimeter of the structure to avoid pulling the steel framing out of alignment. Steel building frames have different tolerances from those discussed previously. Tolerances for steel frame structures make it impractical to maintain precast concrete panels in a true vertical plane. Based on the allowable steel frame variations, it would be necessary to provide for a 3 in. (75 mm) adjustment in connections up to the twentieth story and a 5 in. (126 mm) adjustment in connections above the twentieth story if the engineer/architect insists on a true vertical plane. Connection adjustments of this magnitude are not economically feasible. Therefore, the precast concrete wall should follow the steel frame.

In determining tolerances, attention should be given to possible deflections and rotation of structural members supporting precast concrete. This is particularly important for bearing on slender or cantilevered structural members. If frame deflection is sensitive to location or eccentricity of the connection, tolerances for location or eccentricity should be given.

Consideration should be given to initial and long-term deflections caused by creep of the supporting structural members. Beam and column locations should be uniform in relation to the precast units with a constant clear distance between precast concrete and support elements.

A structural steel frame presents installation and connection problems different from that of a concrete building frame. Structural steel cross sections are relatively weak in torsion compared with concrete cross sections. Structural steel members generally require that the load be applied directly over the web or that the connection be capable of supporting the induced torsional moment. This can require a stronger connection and create installation problems when rolling tolerances of the steel beam approach their limits. When detailing precast elements for attachment to steel structures, allowance should be made in the precast connections, such as sliding connections and oversized holes; for sway in tall, slender steel structures with uneven loading; and for deflections due to thermal effects.

Designs should provide for vertical adjustment of precast concrete panels supported by the steel frame. An accumulation of axial shortening of axially loaded steel columns will result in the unstressed panels supported at each floor level being higher than the steel frame connections to which they should be attached. Sometimes, non-load-bearing precast elements become load-bearing even though the design does not allow for load. This can result in cracking.

The clearance necessary for wall installation depends on wall design, dimensional accuracy of the building frame or other construction to which the wall is connected, and the adjustment limits permitted by connection details. When connections to the face of spandrel beams or to columns are required, more clearance will be needed to install fasteners than when anchors are located on the sides of columns and the top, bottom, or both faces of beams.

4.7—Clearances and tolerances for constructibility

4.7.1 *Suggested minimum clearances*—Clearance, or interface space between members, should be specified to facilitate construction. Suggested minimum clearances are:

- Between precast panels and adjacent precast members—1/2 in. (13 mm).
- Between precast panels and cast-in-place concrete—1 in. (25 mm), but 1-1/2 in. (38 mm) is preferred.
- Between precast panels and steel frame—1 in. (25 mm).
- Between precast panels and the frame of tall irregular structures—2 in. (50 mm).
- Between precast column cladding and column—1-1/2 in. (38 mm), but 3 in. (75 mm) is preferred.

If clearances are practically assessed, they will solve many tolerance problems. The nominal clearance dimension shown on the installation drawings should equal the actual clearance required plus the outward tolerance permitted for the adjacent structural frame. Nominal clearances should be determined on the assumption that the structural frame will be as far out of position in the wrong direction as allowed. Connections should be designed to accommodate clearance plus inward tolerance.

4.7.2 *Connection problems*—Connections should have the maximum adjustability that is structurally or architecturally feasible. Closer tolerances are required for bolted connections than for grouted connections. Connections should provide for vertical, horizontal, and lateral adjustments of 1 in. (25 mm) minimum to accommodate any misalignment of the support system and the precast elements. Location of hardware items cast into or fastened to the structure by the general contractor, steel fabricator, or other trades should be determined with specified tolerances for all site placement. Unless another value is specified by the engineer/architect, tolerances for such locating dimensions should be +1 in. (25 mm) in all vertical and horizontal directions plus a slope deviation of no more than +1/4 in. (6 mm) for the levelness of critical bearing surfaces.

Connection details should provide for the possibility that bearing surfaces are misaligned or warped from the desired plane. Adjustments can be provided by the use of dry-pack concrete, nonshrink grout, or elastomeric pads if the misalignment from the horizontal plane does not exceed 2 in. (50 mm).

When possible, connections should be dimensioned to the nearest 1/2 in. (13 mm). Minimum clearance between parts within a connection should not be less than 1/4 in. (6 mm), with 1/2 in. (13 mm) preferred. Minimum clearance or shim space between various connection elements should be 1 in. (25 mm).

Where a unit is not erected within the tolerances assumed in the connection design, the structural adequacy of the installation should be checked and the connection design should be modified if tolerances are exceeded. No element should be left in an unsafe support condition. Adjustments in the prescribed tolerances should be made only after approval by the engineer/architect.

CHAPTER 5—MATERIALS

5.1—Introduction

Basic materials used in fabrication and installation of precast concrete wall panels are the same as those used in cast-in-place structural concrete, but precast concrete wall panels also make use of special materials, casting techniques, and curing. Exposed aggregates, admixtures, inserts, and specialty coatings are used to enhance aesthetic appearance. This chapter describes the following materials as used in precast concrete panel construction.

- Portland cement.
- Standard and decorative aggregates for exposed facing.
- Admixtures.
- Insulating materials and wythe connectors.
- Reinforcement and inserts.
- Curing materials and sealers.
- Joint sealants and fillers.
- Surface retarders.
- Form release agents.
- Thin brick.

Most of these materials are considered in more detail by other ACI committees.

5.2—Portland cement

5.2.1 *General*—Usual industry practice is to use white, buff, or gray portland cement or a mixture of white and gray cements meeting ASTM C150/C150M-11 requirements for Type I or Type III. White cement usage should be clearly specified when it is required. Cement Types II, IV, and V are seldom used in precast panels. When using any special cement, take every precaution to ensure that early concrete strengths are adequate.

5.2.2 *Single source*—For any given project, enough cement for the entire project should be procured from a single source so all cement is the same brand and type. Some precasters prefer to obtain a single, one-time, one-batch shipment for a given project to minimize color variations. Elimination of color variation is not possible because variables in other materials and in panel fabrication can have effects.

5.2.3 *Storage*—Dry, covered storage areas should be provided for bulk or bagged cement. Bagged cement should be stored on wooden pallets and out of contact with tanks or outer storage building walls where condensation could occur. To avoid pack set, bags should not be stored more than two pallets high, or 7 ft (2.1 m) total height.

5.2.4 *Sampling*—In case of future problems with strength or color uniformity, a sample should be taken from each cement shipment and kept in a full, sealed container at least 6 months or until the shipment is exhausted.

5.2.5 *Mill certifications*—Mill certifications should accompany each shipment that contains the material compositions as well as conformance to the required ASTM standard tests.

5.3—Aggregates for structural or backup concrete

Normalweight or lightweight aggregates conforming to ASTM C33/C33M-11 or C330/C330M-09, respectively, should be used in backup or structural concrete for precast panels.

Aggregates for backup concrete should be stored in clean, well-drained areas in identifiable bins. Bins should be designed to avoid segregation, contamination, or intermixing of different aggregates or aggregate sizes. When aggregate is intended for use with self-consolidating concrete (SCC), gradation, specific gravity, and moisture content are critical and should be measured and monitored frequently.

5.4—Facing aggregates

5.4.1 *Grading*

5.4.1.1 *General*—Uniform aggregates for regular concrete are usually selected by standard sieve sizes to provide a balance of fine and coarse sizes. Grading that combines aggregate sizes to produce the maximum weight of aggregate per unit volume of concrete is preferred. Most concrete mixtures are chosen with this in mind but are often limited on the upper end of the coarse aggregate size by dimensions of the panel to be cast, clear distance between reinforcement, clear distance between the reinforcement and form surface, desired finish, and flow requirements.

5.4.1.2 *Gap grading of facing aggregates*—Because precast concrete panels frequently use exposed aggregate, the desired surface finish, appearance, and texture can dictate fine and coarse aggregate grading. Gap grading can achieve a consistent, uniform panel face with a maximum of aggregate surface exposed. A gap-graded combination of fine or coarse aggregates has one or more sizes missing from the range of standard particle sizes. Producers may elect tighter or more restrictive gradings in an attempt to improve uniformity. Common sizes of gap-graded fine aggregates are 30 to 50 mesh (600 to 300 mm) and 16 to 30 mesh (1.18 mm to 600 mm). Using coarse and fine sizes combined can produce a gap-graded combination that results in less segregation and more uniform surface finish. In SCC, gradation and aggregate proportions may be dictated more by an effort to achieve a stable mixture than the finish. Selecting an aggregate and its properties should satisfy flow requirements and surface finish.

5.4.1.3 *Schedule of sizes*—Table 5.4.1.3 shows four different size gradings established by precast industry aggregate suppliers for use in exposed aggregate precast concrete. This size schedule is not universally recognized, and some aggregate producers may have their own standards. Panel producers should be aware that small aggregates, 1/8 in. (3 mm) and smaller, may pull out during exposed aggregate surface finishing.

Table 5.4.1.3—Typical industry size specifications for exposed aggregate

Sieve opening		Percent of indicated size aggregate passing			
		Size D 1-3/8 to 7/8 in. (35 x 22 mm)	Size C 7/8 to 1/2 in. (22 x 13 mm)	Size B 1/2 to 1/4 in. (13 x 6 mm)	Size A 1/4 to 3/32 in. (6 x 2 mm)
in.	mm	Percent of indicated size aggregate passing			
1-1/2	38	100	—	—	—
1-3/8	35	95 to 100	—	—	—
1	25	30 to 60	100	—	—
7/8	22	20 to 40	95 to 100	—	—
5/8	16	0 to 10	30 to 50	100	—
1/2	13	—	10 to 25	95 to 100	—
3/8	9	—	0 to 10	40 to 70	100
1/4	6	—	—	5 to 20	95 to 100
1/8	3	—	—	0 to 10	15 to 35
3/32	2	—	—	—	0 to 10

5.4.2 *Types and quality of facing aggregates*

5.4.2.1 *General*—Usually decorative facing aggregates are used only in exposed panel faces because of cost. Face layer thickness depends on aggregate size but should be sufficiently thick to prevent backup concrete from showing through the exposed face and eliminate the reinforcing footprint. Face concrete thickness should be 1.5 times the maximum size of coarse facing aggregate but not less than 1 in. (25 mm). Facing aggregate mixtures should be stocked in sufficient quantities from the particular source to complete an entire project. Inappropriate planning may cause unwanted changes in color or texture.

5.4.2.2 *Specific surface color and texture*—Special aggregates for facing include naturally occurring aggregates such as select gravels, granites, traprock, marble, limestone, quartz, quartzite, feldspar, and obsidian. Selection should be based on performance of the facing aggregate in approved panel samples. Approval should be based on fabrication, mixture design, and aesthetic acceptability.

5.4.2.3 *Durability concerns*—Some limestone, marble, and sandstone are not durable on exposed exterior surfaces. All facing aggregates should have proven service records or been shown to be acceptable under laboratory test conditions before being used in precast panels. Appropriate tests include petrographic examination, abrasion resistance, and expansion tests (ASTM C227-10). Facing aggregates that pass laboratory durability testing or have good service histories rarely have problems with alkali-aggregate reactivity. When such a reaction is suspected from a new or unknown combination of aggregates and cement, the aggregate should be examined petrographically and expansion should not exceed ASTM C33/C33M-11 limits. If the limits are exceeded, low-alkali cement with a maximum of 0.6% Na_2O (ASTM C150/C150M-11) or fly ash should be used with the aggregate. Mineral admixtures shown to prevent harmful expansion, such as fly ash, may be used if the matrix color meets architectural appearance requirements.

5.4.2.4 *Staining*—Coarse facing aggregates may contain particles with high iron content that result in unsightly stains. These stains usually appear at a later date due to atmospheric oxidation or carbonation. Selectivity by the panel producer and knowledge of aggregate materials and their service records are the only assurance against long-term iron stains from aggregates. An untried aggregate should be tested for iron-bearing particles according to ASTM C641-09. Aggregates should show a stain index less than 20.

5.4.2.5 *Glass or ceramic aggregates*—Glass or ceramic aggregates used for bright color or special effects should not react with the cement used. The quick chemical test in ASTM C289-07 may be used for detection of glass or ceramic aggregates that are reactive. Ceramic aggregates may exhibit brittleness and breakdown during casting. Glass aggregates have low absorption and good durability, but have low compressive strength and low bond strength with cement paste. Fabrication experimenting and testing of glass and ceramic faced panels is recommended.

5.5—Admixtures

5.5.1 *General*—Chemical or mineral materials may be added to the concrete mixture to bring about specific changes in mixture properties. ACI 212.3R-10 contains limits and recommendations for the use of chemical admixtures, including limits on chloride content of hardened concrete (refer to Section 5.5.4). To protect reinforcement from corrosion, ACI 222R-01 recommends limiting the acid-soluble and water-soluble chloride ion content in hardened concrete. All prestressed concrete and any reinforced concrete exposed to moisture or chloride in service falls into one category and any reinforced concrete that is dry or protected from moisture in service falls into the other category.

5.5.2 *Air-entraining admixtures*—Air-entraining admixtures should be used in all concretes that may be exposed to freezing-and-thawing cycles when saturated with water. The added protection against freezing-and-thawing deterioration far outweighs any loss of strength, porosity, or density. A typical dosage of air-entraining admixture providing approximately 9 percent air in the mortar fraction of the concrete is recommended. Because of the unusual nature of most facing mixtures, a specification for the amount of air-entraining admixture rather than a fixed percentage of air is recommended. Refer to ASTM C260/C260M-10 and C185-08.

5.5.3 *Mineral admixtures and pozzolans*—On rare occasions, where a particularly smooth surface is desired, fine minerals or pozzolans may be added to the mixture. The typical curing period for precast panels is often too short to allow pozzolanic action for increased strength. The most common pozzolans used in concrete mixtures are Type C and Type F fly ashes. Using Type C fly ash minimizes loss of early strength.

5.5.4 *Accelerating admixtures*—Type C and E accelerating admixtures (ASTM C494/C494M-11) reduce concrete setting time and produce rapid early strength gain, which can aid in panel casting operations. Rapid strength gain can also be accomplished with higher cement content, use of Type III high-early-strength cement, heating water and aggregates, or by steam curing. Accelerators containing calcium chloride or thiocyanate ions can contribute to corrosion of reinforcement. Calcium chloride also affects color. Accelerators containing calcium chloride should not be used in precast panels.

5.5.5 *Retarding admixtures*—Type B, D, and G retarding admixtures (ASTM C494/C494M-11) are normally not used in precast concrete wall panels except in hot weather. Retarders delay the time of set and allow longer finishing time. They generally do not fit into a high-speed casting operation.

5.5.6 *Water reducing admixtures*—Type A and F water-reducing admixtures (ASTM C494/C494M-11) are used in precast concrete wall panels to reduce bleed water or increase concrete workability without adding water. This group includes high-range water reducers for difficult placing conditions. Laitance, bleeding, and efflorescence can be minimized by reducing water requirements. Water-reducing admixtures may be helpful in harsh mixtures or where gap-graded aggregates are being used. Water-reducing components should meet the requirements of ASTM C494/C494M-11 Type A, and should be checked for compatibility with the cement and with any air-entraining admixture to be used.

5.5.7 *Viscosity modifiers*—Viscosity-modifying admixtures (VMA) are sometimes used in SCC to enhance the flow of the concrete mixture and reduce segregation.

5.5.8 *Coloring materials*—Pigments and dyes are used to color tone the concrete in precast panels. It is important to have tests or performance records that reliably indicate the color stability of any coloring agent. Experience shows that there is generally poor color stability with organic blacks, blues, and greens.

5.5.8.1 *Pigments*—Pigments commonly used to color concrete are finely ground natural or synthetic mineral

Table 5.6.1—Insulation density, thermal conductivity, and permeability

	Density, lb/ft^3 (kg/m^3)	Thermal conductivity per inch of thickness (h·ft^2·F°/Btu *R*-value)	Water vapor permeability, perm
EPS Type I	0.90 (14.4)	0.278 (3.6)	5.0
EPS Type II	1.35 (21.6)	0.25 (4.0)	3.5
XPS Type IV	1.55 (24.8)	0.20 (5.0)	1.0
XPS Type VI	1.80 (28.8)	0.20 (5.0)	0.80
PIR Type I (Faced)	2.00 (32.0)	0.154 (6.5)	0.03
PIR Type II (Unfaced/felt faced)	2.00 (32.0)	0.154 (6.5)	4.0

oxides. Synthetic oxides are usually more satisfactory because they are manufactured in more shades, have properties that are more consistent, provide better color intensity, and they last longer. Synthetic pigments may possibly react with other products such as retarders or muriatic acid used on concrete facing mixtures. All pigments should be tested before use and should conform to ASTM C979/C979M-10.

Iron oxides produce shades of yellow, buff, tan, brown, red, maroon, and black. Chromium oxide produces green shades. Cobalt oxide produces blue shades. Adding these oxides as a percentage of the cement content by weight produces various shades of the primary color. Amounts in excess of 5 percent by weight of cement seldom increase color intensity. Amounts greater than 10 percent can adversely affect concrete quality and are not recommended.

Pigments used with white cement produce clearer and brighter shades than if used with gray cement. Dry mixing pigment with cement before concrete mixing is preferred. Some cement manufacturers provide premixed or pigmented cements.

5.6—Insulating materials and wythe connectors for insulated sandwich walls

Sandwich wall panels are comprised of rigid board insulation sandwiched between an exterior and interior concrete wythe. The concrete wythes are held together by wythe connectors intermittently placed through the insulation layer.

5.6.1 *Insulation*—Several rigid board insulations are available to provide the thermal and moisture characteristics necessary for sandwich wall panel construction. However, many insulating materials have high initial absorption rates and can absorb water from fresh concrete as it is placed. Because the insulation's thermal performance is typically degraded by moisture intrusion, insulation used in sandwich wall construction should resist moisture absorption or be accompanied by a vapor barrier.

Cellular board insulations made from extruded and expanded polystyrene and polyisocyanurate (PIR or ISO) are used predominately in the construction of sandwich wall panels due to their closed-cell matrix. This closed-cell matrix often results in an increased resistance to moisture intrusion but some closed-cell board insulations contain voids that can absorb moisture and result in diminished overall thermal conductivity.

The thermal conductivity of water is far greater than insulation. When water is introduced into board insulation, thermal resistance is reduced. The actual amount of water vapor that passes through a material by diffusion is called a perm. Lower perm ratings mean more resistance to vapor flow. Closed-cell insulations with a water vapor permeance of 1 perm or less are considered vapor barriers and can act on their own to resist moisture intrusion. Closed-cell insulations with a water vapor permeance greater than 1 perm should be protected from direct contact with fresh concrete by a vapor barrier. Table 5.6.1 shows insulation density, thermal conductivity, and permeability for different insulating materials.

5.6.2 *Wythe connectors*—Wythe connectors connect interior and exterior wythes through the insulation. Wythe connectors are classified as a structurally composite or structurally noncomposite, depending on their ability to transfer shear forces between wythes. Shear force transfer between wythes makes sandwich-wall panels composite. Structurally noncomposite connectors should accommodate differential thermal movements that occur because of the large thermal fluctuations of the exterior wythe. Structurally composite connectors should transfer shear forces between wythes. Some structurally composite connectors cannot accommodate any thermal movement whereas some can accommodate partial thermal movement.

5.6.2.1 *Concrete*—Continuous or intermittent concrete blocks (known as hard spots, ribs, or block-outs) can be used as wythe connectors. This connection type is often used to produce structurally composite wall panels and requires displacement of the insulation. This creates a thermal bridge in the system that increases the amount of energy lost or reduces the *R*-value of the entire panel.

5.6.2.2 *Steel ties*—C- or M-shaped ties are used in the construction of structurally noncomposite wall panels. Steel ties have a high thermal conductivity.

5.6.2.3 *Steel trusses*—Steel trusses with thin wires have been used in the construction of structurally composite wall panels. Steel trusses, like steel ties, have a high thermal conductivity.

5.6.2.4 *Glass fiber-reinforced polymer (GFRP) composite connectors*—GFRP composite connectors are manufactured from continuous glass fibers pulled through thermoset vinyl ester resin. GFRP composite connectors can be used in structurally noncomposite or structurally composite wall panel construction, depending on the type of connectors used. GFRP composite connectors have a low thermal conductivity. GFRP products should meet the requirements of ACI 440.6-08.

5.6.2.5 *Carbon fiber-reinforced polymer (CFRP) shear trusses*—CFRP shear trusses are cut from CFRP grids manufactured by aligning continuous CFRP strands in an orthogonal pattern and impregnating them with an epoxy resin that is cured. Used in structurally composite wall panel construction, CFRP shear trusses have a low thermal conductivity. CFRP products should meet the requirements of ACI 440.6-08.

5.7—Reinforcement

Reinforcement for precast panels includes prestressing materials, deformed bars, welded wire reinforcement, and CFRP mesh. Reinforcement includes wythe connectors as described in Section 5.6.2.

5.7.1 *Deformed reinforcing bars*—Deformed reinforcing bars are manufactured by hot rolling deformations onto steel and are made in accordance with ASTM A615/A615M-09 (billet steel), and ASTM A706/706M-09 (low-alloy steel). Bars are normally used in straight lengths but can be bent to form hooks required for anchorage purposes. ASTM A496/A496M-07 presents requirements for deformed wire used as concrete reinforcement.

5.7.2 *Welded-wire reinforcement*—Welded-wire reinforcement (WWR) is available in a wide variety of mesh spacings and wire gauges with both plain and deformed wire being used. WWR should be manufactured in accordance with ASTM A185/A185M-07 and A497/A497M-07 for plain and deformed wire, respectively.

5.7.3 *Prestressing materials*—Steel wire, bar, and strand for prestressed concrete should meet requirements of ASTM A416/A416M-10, A421/A421M-10, and A722/A722M-07.

5.7.4 *Corrosion protection of reinforcement*—When aesthetic considerations reduce concrete minimum cover below that ordinarily specified or recommended, reinforcement in precast concrete panels thinner than 4 in. (100 mm) may be susceptible to corrosion. In such cases, the long-term appearance and durability of the panels may require corrosion-resistant reinforcing materials. Stainless steel reinforcement, reinforcement clad with stainless copper, and fiber-reinforced polymer (FRP) reinforcement, such as CFRP grids, are corrosion-resistant base materials that can be used.

5.7.4.1 *Galvanizing*—Galvanized welded-wire reinforcement is readily available and relatively low cost compared to the unprotected product. Galvanized reinforcing bars are not as readily available and the cost may be substantial. Galvanizing procedures should conform to ASTM A767/A767M-09 and A153/A153M-09, including supplementary requirements. Minimize or avoid using galvanized or copper bars by proper design, maintenance of minimum cover, and panel manufacture so that bar location, concrete placement, and consolidation are precisely controlled.

5.7.4.2 *Epoxy coating*—Epoxy-coated reinforcing bars (ASTM A775/A775M-07) and welded-wire reinforcement (ASTM A884/A884M-06) have been used extensively in severe exposure environments, but only minimally in architectural precast panels. ACI 222R-01 discusses the corrosion mechanism and corrosion protection in detail. Development length should be increased for epoxy-coated bars as required by Section 12.2.4 of ACI 318-08. These bars are a good corrosion-resistant alternative if the coating is uniform. Bars can be coated when straight and subsequently bent with no effect on coating integrity. If coating is damaged or nonuniform, bars should be touched up with a commercially available epoxy compound to prevent serious corrosion. Bar tying should be with nylon or GFRP-coated tie wire rather than black wire. Bar supports should be stainless steel, epoxy-coated, or solid plastic.

5.7.4.3 *Other coatings*—Other coatings available for corrosion protection include paints such as inorganic zinc-rich coatings, epoxy paints, and certain proprietary chemical compounds that combine with oxide coatings to form a protective layer. These materials may be brush, bath, or spray applied. When evaluating these coatings, consider known performance characteristics and test data.

5.7.4.4 *Carbon fiber-reinforced polymer (CFRP) grids*—CFRP grids may be used instead of welded-wire reinforcement to reinforce concrete structures where corrosion resistance and thinner concrete sections are desirable. They are produced in a fabrication process where continuous CFRP strands are aligned in an orthogonal pattern, impregnated with an epoxy resin, and cured to form a grid. They are typically thin and flexible and usually supplied on rolls. Like welded-wire reinforcement, carbon strand spacing can be varied in each direction to supply the necessary tensile strength (ACI 440R-07).

5.7.4.5 *Stainless steel welded-wire reinforcement*—Stainless steel welded-wire reinforcement is available and can be used instead of carbon steel welded-wire reinforcement where corrosion protection is desired.

5.8—Inserts and miscellaneous hardware

Inserts are cast into a panel for lifting, holding, or attaching the precast panel to other structural members. Drilling inserts into place after casting is not recommended unless changes to the cast-in inserts occurred and a field solution is required.

Items such as channel sections, framing, studs, anchors, expansion anchors, and inserts should be made from permanently ductile materials. When reinforcing bars are used as anchors or inserts, follow precautions (refer to Section 7.4.2) to ensure adequate strength and ductility when their connections are welded. Brittle materials such as gray-iron castings should not be used. Specifications for bolts include ASTM A307-10, A325-10, and A490-10. Specifications for stud welded anchors include ASTM A108-07 and A496/A496M-07.

5.8.1 *Expansion anchors*—Expansion anchors should conform to applicable bolt specifications and be performance tested in accordance with ASTM E488/E488M-10. All items should have documented chemical and physical properties and be used in accordance with the manufacturer's recommendations and test data.

5.8.2 *Corrosion protection*—Where corrosion protection is required for embedded or exposed hardware, noncorrosive materials such as stainless steel in accordance with ASTM A276-10, or a coating such as zinc, cadmium, epoxy, or corrosion-resistant paint may be used. Protective coatings should not interfere with the fit of nuts onto the threaded portions of fasteners. Hex nuts and washers, or other matching hardware used with exposed insert connections, should be zinc- or cadmium-plated. Using hex lock nuts with nylon locking washers is suggested.

5.9—Curing materials and sealers

5.9.1 *Curing materials*—Although not generally used, curing compounds are preferred over water, burlap, or other wetted coverings where additional curing of the concrete is required. A wide range of curing compounds is commercially available. They should be supported with test data and user experience before acceptance. Steam curing is discussed in Section 6.7.3.2. Curing compounds and sealers may have to be removed if the panel surface is to be painted.

5.9.2 *Surface sealers*—Using clear, protective, water-repellent sealers to maintain panel appearance is an area of controversy with panel producers. The potential improvement of weathering qualities in urban or industrial areas may justify sealer use, as a sealer may protect exposed concrete from airborne industrial chemicals. Laboratory exposure tests and long-term outdoor exposure plots have yielded a wide range of results. Some sealers produce severe discoloration within exposure periods varying from 1 week to several months. Panel surfaces that have been sealed may discolor due to the sealers attracting hydrocarbons to the sealer surface, having little resistance to discoloration by the sun's ultraviolet rays, or being affected by temperatures of 145°F (62.8°C) or more.

Tests show that sealers do not improve resistance to freezing and thawing. Resistance to freezing and thawing is best achieved with air-entraining admixtures, as outlined in Section 5.5.2.

Sealer use should be based on previous experience and careful study of test data for performance in the proposed environment. Sealers should be applied in strict accordance with the manufacturer's recommendations. Sealers generally should not be applied on surfaces that will contact joint sealants.

5.9.2.1 *Silicone sealer performance*—The use of silicone-based sealers is not recommended. Surfaces treated with silicone formulations vary widely in performance. Experience with silicone sealers indicates they should not be used on exposed quartz aggregates and that durability is marginal when used on other aggregates. In urban areas, some silicone sealers attract airborne hydrocarbons, resulting in premature discoloration of white or light-colored panels within a short period. Silicone sealers interfere with the bonding of patches and prevent the bonding of joint sealants. If used, silicone-based materials should be applied only after patching and joint sealing are completed.

5.9.2.2 *Other sealers*—Better performance results have been obtained with methyl methacrylate forms of acrylic resin on exposed aggregate surfaces. Satisfactory results have also been achieved with other acrylic copolymers, silanes, and siloxanes.

A wider range of acceptable sealers is available on less delicate surfaces such as plain or ribbed concrete panels. Sealers that do not perform well on exposed aggregate surfaces or very light-colored surfaces are often acceptable on plain or ribbed concrete.

5.10—Joint sealants and fillers

5.10.1 *Mortars*—Cement mortars are not ductile and cannot accommodate panel movement. Although they are not suitable as sealants, mortars may be used with other sealers for packing connection joints. Mortars are preferred for the base of load-bearing panels supported by shims.

5.10.2 *Elastomeric sealants*—Only elastomeric materials should be used as sealants in precast panel installation. Elastomeric sealants (caulks) include polysulfides, silicones, and urethanes. They may be one- or two-part compounds and both are preferred over oil-based types. Despite higher initial price, elastomeric sealants are preferred because of lower maintenance costs, better weather tight joints, and longer life. Consult ASTM C1193-11 for detailed information.

Nonstaining elastomeric joint sealants should be selected to prevent bleeding and heavy dirt accumulation. High-performance one- or two-part sealants such as polysulfides, urethanes, silicones, or other sealant material are recommended for weatherproofing joints in precast panels. These sealants should withstand joint movements of at least ±25 percent. If greater sealant movement capacity is required, consult with manufacturers of low-modulus sealants. The sealant selected should match the color of the precast panel as closely as possible to reduce the visual effect of variations in joint dimensions.

5.10.3 *Joint fillers*—Backup fillers are needed in joints to control sealant depth, facilitate tooling of the sealant, and serve as a bond breaker to prevent the sealant from bonding to the back of the joint. Filler material should be nonstaining to the sealant. Asphaltic (bitumastic) fillers should not be used. The sealant manufacturer can advise on filler materials that are compatible with the selected sealant. The recommended shape factor should also be listed. Acceptable fillers are those that compress into the joint and respond to panel movement. A round filler profile provides maximum edge area with minimum cross section for best sealant adhesion. The best filler profile is a rod of spongy or foamed material that is closed cell to prevent moisture retention.

5.11—Chemical retarders

5.11.1 *General*—Chemical retarders temporarily delay the hardening of cement paste at the surface of the precast panel. After the base concrete of the panel hardens (normally overnight), the retarded cement paste is removed by brushing, high-pressure water washing, or sandblasting to expose the aggregates. Brushing or water washing will not change the natural look of the aggregates, but sandblasting may dull the surface.

Two types of chemical retarders are used in precast panel fabrication. Form retarders are usually fast-drying solvent-based materials applied to the form surface. These retarders resist the abrasion inherent in the placement of concrete. Surface retarders are water-based materials applied to the top surface of freshly-placed concrete. They are usually applied with garden-type spray applicators. Before the retarder is sprayed on, additional aggregate may be placed on the surface and troweled in to provide a more uniform finished surface.

5.11.2 *Depth of reveal*—Form and surface type retarders are used to etch the concrete to depths that allow for design flexibility. As a general rule, the retarder should expose not more than 40 percent of the aggregate diameter at the surface. When used, retarders can produce finishes of the lightest reveal, removing only surface skin, to a deep reveal, removing aggregates up to 1-1/2 in. (38 mm).

5.12—Form release agents

5.12.1 *General*—Modern release agents are formulated from a variety of ingredients to perform several functions. Their primary purpose is to release the panel (aid in debonding) from the form. Other functions include:

- Minimizing or eliminating bug holes and stains.
- Minimizing form clean up time.
- Keeping cementitious materials from building up on the form facing.
- Contributing to the fabrication of high visual impact concrete surfaces.

Desirable attributes include:

- Not interfering with the bonding of construction, architecturally aesthetic materials, or both, to the hardened concrete surface.
- Not degrading and staining form facing materials.
- Not staining concrete when steam curing is used.
- Being easy to apply in all seasons.

5.12.2 *Chemically active release agents*—Chemically active release agents are the most common. Their releasing ability is the result of a chemical reaction between the free lime from fresh cement paste and chemicals in the release agent coating the form surface. This reaction produces slippery, water-insoluble soap or grease, which provides for easy form removal. Typically, the chemically active ingredients are fish oils, vegetable oils, animal fats, or combinations thereof.

5.12.3 *Emulsion type agents*—Some release agents use water emulsions for a carrier instead of petroleum-derived oil. Some emulsions are chemically active agents, whereas others facilitate form release by producing a barrier film, much like fuel oil does. Generally, emulsion type release agents will not harm form facing materials that are sensitive to petroleum-derived oils. Cold weather operations require storage and use considerations different from other release agents.

5.12.4 *Petroleum-derived agents*—Release agents made entirely from petroleum-derived oils, such as fuel oil and kerosene, function by producing a barrier between the form face and the concrete. This barrier-type release agent generally causes more bug holes, staining, and poorer form release than chemically active types.

5.12.5 *Applying release agents to formwork*—Release agents should be applied in a thin uniform coating on clean, dry form facings. Usually this is done by spraying. The release agent should be applied in a manner and scheduled to avoid coating the reinforcement.

CHAPTER 6—PANEL FABRICATION AND DELIVERY

6.1—General requirements

6.1.1 *Preparation of design calculations, fabrication, and installation drawings*—The precast manufacturer prepares installation and fabrication drawings for the precast panels. All necessary details for the fabrication, handling, and installation of the precast products from the specifications and architectural, site, and structural drawings are needed to prepare installation and fabrication drawings. Installation drawings and hardware from other trades should be provided within contractual schedules. Detailing methods vary with the manufacturer, but elevations and horizontal dimensions shown should locate and mark each precast element and give its relationship to windows, openings, and adjacent building components. Details should provide size, shape, dimensions, and profiles of each member. Connections, reinforcement, and individual mark numbers should be shown. Installation drawings should show the following:

- Design gravity, wind, and seismic loads.
- *R*-value for insulated panels, including thermal analysis and method used.
- Location and details of hardware embedded in or attached to the structural frame, between precast panels, or both.
- Handling loads and additional reinforcement required for transportation and installation stresses.
- Proposed installation sequence, if required.
- Unless otherwise specified, temporary bracing for vertical panels.
- Method of erecting panel plumb (adjusting the vertical orientation) and adjusting connections.
- Signing and sealing of drawings by a licensed design professional.

Joint and joint sealant details should be shown where applicable. Further, special fittings such as stripping, lifting or installation inserts, anchoring details, reglets, cutouts, pipe sleeves, other embedded items and openings should be carefully located and dimensioned. Drawings and calculations prepared to show the aforementioned should be forwarded to the general contractor and the engineer/architect for approval as recommended in Section 1.3.6.

6.1.2 *Fabrication facilities*—Precast panel fabrication facilities vary widely. It is recommended that precast concrete plants are certified in accordance with the Precast/Prestressed Concrete Institute (PCI) Plant Certification Program. Fabrication facilities are affected by the size, weight, and volume of the products produced and by the climate and proximity of marketing areas. Generally, plants in regions with winter climates are fully enclosed or indoors, and plants in regions without winter climates may be outdoors. When specific project requirements warrant casting on the job site, a site precaster faces many more challenges than a plant precaster does. Some possible challenges include lack of tightly controlled batching conditions, unfavorable curing and protection from the elements, difficulty obtaining skilled labor force, and lack of management or a supervisory group experienced in precasting operations.

Recommendations in this guide help overcome these possible deficiencies. The fabrication facility, whether in a plant or at the site, should provide the following:

- Facilities to receive and store raw materials such as cement, aggregates, reinforcing steel, and insulation.
- Facilities for controlled proportioning and mixing of concrete.
- A covered area for fabrication molds and forms.

Fig. 6.1.3—Precasting plant and storage yard.

- An area for assembly and fabrication of reinforcement.
- Facilities for prestressing precast wall panels, if required.
- Appropriate protection (depending on climate) for concrete placement operations.
- Additional space for finishing and curing operations.
- Adequate yard space for convenient and proper storage.
- Equipment capable of lifting and handling panels of the size and weight to be manufactured.

6.1.3 *Fabrication and storage areas*—Facilities for batching and mixing concrete should be in accordance with ACI 304R-00, which provides details on batching of aggregates, cement, admixtures, and water. Equipment should be available to determine the amount of free moisture in the coarse and fine aggregates. Moisture compensation determined by devices using conductivity varies with aggregate density and is not recommended. Facilities should be protected and monitored to prevent frozen aggregates from being introduced into the concrete. Mixing equipment should be adequate for the size of the operation and capable of thoroughly and uniformly mixing concrete constituents. Panel fabrication areas should be protected against rain, wind, dust, direct sunlight, and have controllable heat to prevent concrete temperatures from dropping below 50°F (10°C). Panel storage areas should provide for easy access and ready handling of stored units (Fig. 6.1.3). Storage surfaces should be clean, hard, level, and well-drained to permit well-organized storage and minimize or prevent warping, bowing, chipping, cracking, discoloration, staining, or soiling of the precast panels. Insulated sandwich panels should be checked by plant engineers to determine how many panels can be stacked in one pile without damaging the panels at the dunnage locations.

6.2—Molds (Forms and casting beds)

6.2.1 *General*—Wood, concrete, steel, plastic, plaster, polyester resin reinforced with glass fibers, and combinations of these have been used successfully as a mold or form material for precast panels. Long line steel beds are common for prestressed structural panels and wood molds are common for smaller, less repetitious architectural panels. Various patterns made of rubber, pressed metal, or vacuum-formed GFRP can be combined with basic materials for special effects. For complicated details, molds of plaster, gelatin, or sculptured sand have been combined or reinforced with wood or steel, depending on the size of the panel to be cast. Example of molds and a panel stripped from its mold are shown in Fig. 6.2.1(a) and (b).

The panel producer typically selects the appropriate mold based on price, maintenance, method of consolidation, reuse, panel details, possible salvage, and desired finish and texture of the product. Where the engineer/architect requires a special mold or finish or a particular mold material, these requirements should be clearly set forth in the contract documents.

6.2.1.1 *Dimensional stability and integrity*—All molds, regardless of material, should conform to the shape, lines, and dimensions of the precast panels to be produced. They should be sufficiently rigid to meet the casting tolerances recommended in Chapter 4. Examples of items to be

Fig. 6.2.1(a)—Mold for casting precast panel.

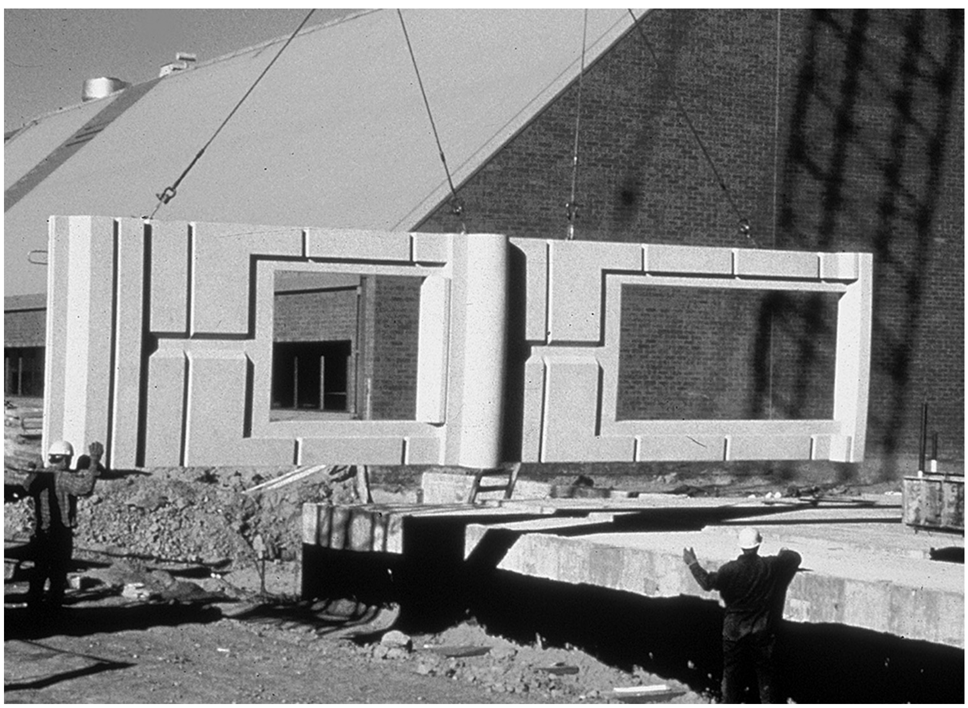


Fig. 6.2.1(b)—Panel stripped from mold.

addressed during the design of the molds include tripping operations and dimensional changes caused when self-stressing forms are used. (Self-stressing forms do not use abutments to resist stresses developed when the strands are tensioned.)

For molds longer than 20 ft (6 m), allowance for shrinkage and thermal expansion or contraction should be considered in the design of the master pattern, the mold, or both. Master molds (detailed in MNL-122-07) are sometimes used to cast panels of several different designs by pre-engineering a number of mold adjustments (Fig. 6.2.1.1).

6.2.2 *Steel casting beds and steel molds*—Long-line steel casting beds are commonly used in precast plants to produce large quantities of panels. Reveal strips or form liners can also be placed on the casting beds to add architectural features. Most structural and insulated sandwich wall panels are produced on steel casting beds. The prestressed anchorages (stressing bulkheads) at both ends of the beds are typi-

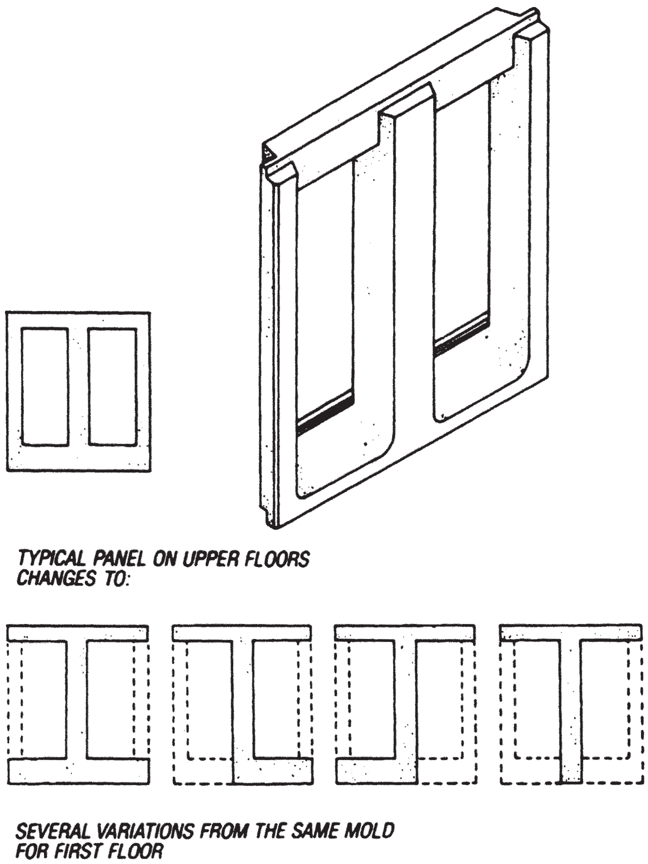


Fig. 6.2.1.1—Master mold for large precast panels.

cally designed to be anchored into the ground and do not transmit any load into the bed. Steel angle side forms are secured to the casting bed by spot welding or magnets. The ends of each panel on the casting bed are separated by steel or wooden bulkheads. Bulkheads should have holes to allow the prestress strands to pass through and are usually stripped from the casting bed along with the panel.

Steel molds are often selected for precast members when numerous assemblies and disassemblies of the mold will be required. Properly designed steel molds have the greatest potential for reuse; they need be discarded only when damaged, or when they show surface imperfections from drilling for changes or from alteration. Steel molds should be well-braced and examined for bulging or buckling during storage or transportation. Dimpling, twisting, or bending can occur if the form surface is not properly stacked for storage.

When steel plates are used for the mold base, use a single piece that has been stretcher-leveled in the steel plant. Joining two or more steel plates by welding to form a flat surface is difficult due to distortion from the heat of the welding operation. If joining is required, welds should be ground smooth and coated with an epoxy or similar material to hide joint imperfections. A test section should be cast at the weld joint to determine that the joined area can produce an acceptable finished product. It is best to minimize casting over a welded form or bed joint. If a prestressing force is to be applied to the form, the self-stressing form should be strong enough to resist the prestressing force without buckling or wrinkling.

6.2.3 *Concrete molds*—Concrete can be formed into many shapes, has excellent rigidity and dimensional stability, and can be reused several times. Concrete molds are manufactured by casting over a master model fabricated to very close tolerances. This master model may be used to produce a series of identical molds. Frequently, concrete molds are treated with polyurethane or epoxy to reduce mold repair and improve release capability. These resins and other coatings render the concrete mold nonabsorbent and produce a more uniform finish on the precast product. Concrete molds may be adapted to become a self-stressing form for use in prestressing a concrete panel. When concrete molds are used, adequate draft should be provided on all surfaces in the direction of stripping or removal so that the product may be easily lifted without damaging the panel or the mold.

6.2.4 *Wood molds*—Wood molds can be simple when relatively small, flat panels are being produced, or they can be elaborate, complicated molds of unusual shapes and large dimensions. Wood molds should be treated to prevent excessive absorption, maintain uniformity of panel finish, and stabilize form dimensions.

Periodic renovation of wooden molds is necessary. Care should be exercised to ensure that multiple uses do not cause the mold to swell or bulge. Mold dimensions should be checked after each use. Wood molds should not be used if steam curing will occur before stripping concrete from the mold. High-quality craftsmanship and joinery are necessary to achieve joints that are of acceptable appearance. Panelization should be preplanned and subject to engineer/architect approval.

6.2.5 *GFRP molds*—GFRP produced from polyester or epoxy resins are widely used because they are easily molded into complex shapes and can impart a variety of patterns to the finished product. Properly designed GFRP molds have excellent performance and reuse expectancy. The mold surface may be repaired as needed.

GFRP molds have a low modulus of elasticity and are somewhat flexible, even though they have excellent tensile strength. If the mold is entirely GFRP, it should be well supported along edges and flat areas. This may be accomplished by reinforcing it with lumber, steel shapes, or other materials as an integral part of mold construction. This mold type is frequently designated a mold liner and requires a mother mold to provide adequate support.

The high-gloss finish imparted to a precast panel by some mold surfaces and mold liners (generally GFRP) may be desirable for indoor decoration. When used for exterior work, weathering may cause the glossy finish to disappear in a non-uniform manner. Crazing and other minor surface imperfections may be more apparent when concrete is cast onto a GFRP mold. Avoid high-gloss finishes on exterior work, unless the panel producer can show successful installations of this finish in a similar climate.

6.2.6 *Form liners*—Textures ranging from muted expression to bold relief are obtained with different types of form liners (Fig. 6.2.6). Draft should be considered for all liners types to prevent chipping or spalling during stripping. Rubber matting is an effective liner that accurately reproduces complex patterns on the concrete surface. Rubber is generally satisfactory, but it should be tested for possible staining or discoloration of the concrete. Trial castings can determine the best time for stripping to ensure the surface remains intact and the liners can be reused.

Wood liners such as boards, plywood panels, or nailed-on inserts work well. Wood liner surfaces should be sealed to prevent moisture absorption and then lightly coated with a form release agent before casting.

Vacuum-formed GFRP sheets can provide varied patterns on textured or glossy-smooth concrete surfaces. The extremely fine finish of GFRP-formed concrete enhances the integral colors and because of high reflectivity, smaller amounts of pigment are required to obtain a given color intensity. Glossy and smooth surfaces are best for indoor rather than outside exposure.

Polyethylene film laid over uniformly distributed cobblestones provides a dimpled surface. Polystyrene foam, shaped and attached to the form, leaves deeply impressed designs after removal from the concrete face.

6.2.7 *Verification and maintenance*—Molds should be checked in detail after construction and before the first product is made. A complete check of the first product from the mold further verifies mold adequacy. Checking the mold by evaluating the product is feasible only where a product can be identified by the specific mold in which it was cast.

Molds should be cleaned between castings and kept in good condition to provide a uniform product of high quality. Steel forms should be carefully maintained to avoid concrete discoloration from iron oxides. Wood loses its protective coating, absorbs moisture, and may swell or warp. Weldments loosen, joints may open, rubber sealing strips erode, and side rails bow due to daily fabrication. It is necessary to check molds regularly, at least once a week, for soundness, surface and dimensional stability, and to repair damage before it affects product quality.

Forms should be reassembled within the dimensional limitations specified for the product on the shop drawings. Form squareness should be checked by comparing diagonal measurements between the form corners. Bulkheads, templates, and similar equipment influencing the accuracy of dimensions and alignment should be regularly inspected and maintained. If more than one form is used to produce a given unit, a comparative dimensional check should be made before casting the initial precast concrete panels.

All positioning holes or slots holding any cast-in materials in position should be checked to ensure that continuous mold use will not create wear and exceed acceptable tolerances. When using wood molds, these clamp-on areas should be protected with corner plates.

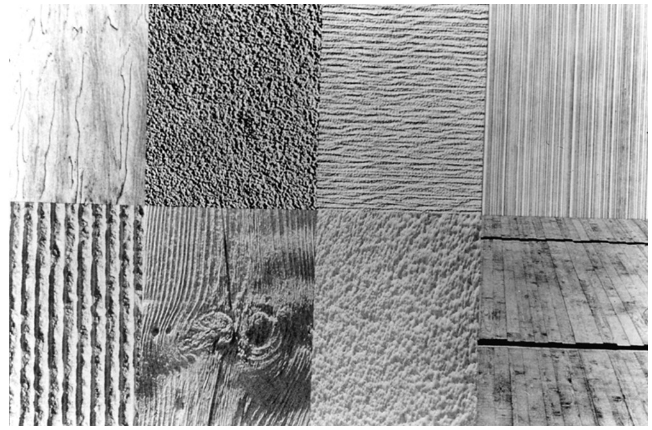


Fig. 6.2.6—Form liner relief patterns.

6.3—Concrete proportioning and mixing

6.3.1 *Introduction*—Information on mixture proportions should be recorded and kept at the concrete batching plant. Although the same technology used for making cast-in-place concrete should be considered in precasting, specific mixture proportions and mixing procedures differ from those for conventional concrete, particularly in the emphasis on finish and durability of the concrete surface. Precast manufacturers usually design and control the concrete used for the precast product based on several factors:

- Finish, size, and shape of units to be cast.
- The consolidation method should be known to determine required workability.
- Maximum size of coarse aggregate.
- Required compressive strength.
- Required surface finish as it affects the ratio of coarse to fine aggregate.
- Exposure to severe weather or environmental conditions.

6.3.2 *Water-cement ratio and consistency (slump)*—With given quantities of cement and aggregate and proper curing, the quantity of mixing water determines concrete strength. Use minimum water to prevent a substantial decrease in strength and durability. Excess water in the facing mixture, backup mixture, or both, can be removed before initial set by a vacuum process, application of hygroscopic materials, or low-slump mixtures.

Stiff mixtures using minimum cement and only enough water to hydrate the cement are economical only in terms of material costs. These mixtures generally require more placing labor, and these added placing costs may more than offset any material cost savings. The use of SCC is popular because precasters recognize the savings in placing labor can more than offset higher material costs.

Variation in the water-cement ratio (*w/c*) can affect color uniformity in architectural panels. The *w/c* should be consistent from batch to batch from the beginning of the project to the end because lack of color uniformity increases the possibility of precast concrete panel rejects.

Concrete mixtures should always have consistency and workability suitable for the project conditions. Heavily reinforced thin sections require a more plastic mixture than large members with little reinforcement. High-range water reducers can increase workability while maintaining a relatively low *w/c*. It is important that the specifier realize that even with the same proportions, slump may vary with environmental conditions and normal variations in materials.

Concrete mixtures using natural sand and gravel aggregates require less water for workability than concrete mixtures using crushed sand and crushed coarse aggregate. The shape and size of the aggregate affect water demand, which in turn affect the *w/c*.

6.3.3 *Proportioning*—Concrete mixtures should be proportioned in accordance with ACI 211.1-91 and ACI 211.2-98 to produce a specified compressive strength of at least 5000 psi (35 MPa) measured at 28 days on either 4 x 8 in. (100 x 200 mm) diameter cylinders or 6 x 12 in. (150 x 300 mm) diameter cylinders. Some decorative aggregates have characteristics that do not permit attainment of compressive strength. Caution is advised in selecting such aggregates.

The objective of proportioning is to achieve a combination of materials that provides the required performance and qualities of the hardened concrete. Concrete mixtures, at a minimum, should be proportioned to achieve the desired performance with respect to strength, absorption, and resistance to freezing and thawing as appropriate to the intended environment.

For normalweight aggregate concrete mixtures, the ratio by volume of fine aggregate to coarse aggregate usually is on the order of 1:3 for facing mixtures. Standard mixtures are usually in the range of 1:1 to 1:2. For lightweight aggregate concrete mixtures, volume ratio varies depending on the type of lightweight aggregate used. The aggregate producer should be consulted about specific material characteristics and recommended mixture designs. A lower ratio of fine to coarse aggregate results in a more uniformly textured finish caused by a maximum concentration of coarse aggregate in the facing mixture. All mixtures for panels exposed to freezing and thawing should include entrained air for increased durability.

6.3.3.1 *Facing and backup mixtures*—Differing aggregate grading and mixture proportion designs for facing mixture concretes make it impossible to recommend a given percentage of air for these mixtures. Consult MNL-117-96 for additional information.

Standard mixtures may be used as backup mixtures if the physical characteristics are similar to the facing concrete. Where a precast unit consists of a face and backup mixture, the mixtures should have similar shrinkage, thermal coefficients of expansion, and modulus of elasticity to avoid undue bowing or warping. Consequently, these mixtures should have similar water-cement and aggregate-cement ratios. Combining a normalweight face mixture and a backup concrete with lightweight aggregates may increase bowing or warping.

6.3.4 *Mixing*—Mixing procedures used in the manufacture of precast wall panels vary due to the variety of equipment and methods of panel fabrication. To maintain batch-to-batch uniformity, materials should be properly sequenced and blended during mixer charging. Good mixing practices include the following:

- Mixer should be operating while all materials are being charged.
- Admixtures should enter the mixer in accordance with the admixture manufacturers' recommendations and be charged into the mixer at consistent times during the mixing sequence.
- Pigments should be premeasured and batched in accordance with the pigment manufacturers' recommendations.
- Where mixtures of 1 yd^3 (0.76 m^3) or less are used, aggregates may be placed into the mixer first and then the cement and water introduced together.

6.3.4.1 *Mixing time*—After all materials have entered the mixer, they should be mixed for at least 1 minute, or as recommended by the mixer manufacturer, until all ingredients are thoroughly distributed and the mixture is homogeneous. All concrete should be discharged while the mixer drum or blades are rotating. Required mixing time varies with characteristics of the concrete mixture and mixer. A timer should be used to ensure the same mixing time for identical-size batches. Pan-type mixers designed for horizontal countercurrent forced mixing are better for very-low-slump concrete (0 to 1 in. [0 to 25 mm]).

6.3.4.2 *Cold weather*—When heated water or aggregates are used to warm the mixture and satisfy cold weather requirements, the addition of cement should be delayed until after the aggregates and water have entered the mixer and have been thoroughly mixed for at least 1 minute. This allows the water or aggregates to cool sufficiently to avoid flash set when the cement is placed in the mixer.

6.3.4.3 *Hot weather*—If the aggregates and water are 100°F (37.8°C) or higher when combined, mixture constituents should be cooled before mixing to avoid flash set, cold joints, or slump loss. Flake ice or crushed ice that will melt completely during mixing should be substituted for all or part of the mixing water. To provide products of uniform color, it is important to control concrete temperature between 90 and 50°F (32.2 and 10°C) throughout all seasons.

6.3.4.4 *Lightweight concrete*—Most lightweight aggregates should be prewetted before introduction to the mixer. This eliminates loss in workability due to rapid absorption of mixing water. Lightweight aggregate and sand, if used, and most of the water are normally mixed thoroughly before the cement and remaining water are added.

6.3.4.5 *Architectural concrete*—Architectural concrete requires uniform mixing practices. Mixers should be cleaned after each period of fabrication. Blades or liners should be adjusted or replaced per manufacturer's recommendations to ensure sufficient mixing. When facing mixtures of pigmented concrete with buff or white cement are used in conjunction with gray cement backup concrete, separate mixers and handling arrangements are required. Alternatively, when separate mixers are not available, equipment should be flushed several times and completely cleaned to remove all concrete residue before being used for mixing where specialty cements or pigments are required.

6.4—Reinforcement and wythe connectors

6.4.1 *Prestressing*

6.4.1.1 *General*—Structural and insulated sandwich-wall panels are typically prestressed for handling wind loads, eccentric axial loads (for load bearing panels), and large dock door openings, and to counteract thermal bowing. Architectural panels are sometimes pretensioned or post-tensioned to avoid cracks, control warping and bowing, or reinforce particularly large units. Firm anchorage of the prestressing steel in a prestressing bed or in suitably designed individual molds is necessary. When the prestressing force is released, concrete compressive strength should be sufficient to meet design and handling requirements of the precast panel. In the case of prestressed architectural panels, special attention should be paid to the transfer of prestress force to the panel, particularly if it is a heavily sculptured precast panel or the panel has many openings.

Accurate strand location is important to avoid inducing permanent bowing or warping. Strand ends should be recessed and backfilled with epoxy special grout, or otherwise carefully protected to avoid corrosion.

Strands are normally tensioned in two increments. The first increment applies sufficient load to the strands to straighten them, eliminate slack, and provide a starting point for measuring elongation. The second strand stressing increment is then applied until the strands reach final stress and elongation. Gauge readings and elongation measurements should be taken and recorded for each strand being stressed.

Prestressing strand, rod, or wires should never be welded. The high temperature may produce crystallization and cause the steel to lose a considerable amount of strength and fail when under tension.

6.4.1.2 *Stringing the strands*—Strands are normally supplied in reelless packs where the strands can be pulled from the spool center. They should be placed in the form in a way that avoids entanglement during the stressing operation. Strands for pretensioned products should be free of dirt, oil, grease, or any foreign substance that can affect their bond to concrete. Strand chucks should be clean, well-lubricated, crack-free, and capable of anchoring the loads induced by the strand without allowing excessive slippage.

6.4.1.3 *Jacking*—Hydraulic jacks with gauging systems are normally used to tension strands. Hydraulic gauges should be accurate to within 2 percent of the maximum applied pressure. Strand force should be determined by observing jack gauge pressure and measuring strand elongation. The two control measurements should agree with their computed theoretical values within a tolerance of ±5 percent. Additionally, these two values should algebraically be within 5 percent of each other. If strand readings are not within this range, tensioning should be stopped and corrective measures taken. Typically, elongation starting points are marked after the initial 3000 lb force (13.3 kN) is applied to the strand to remove any slack.

6.4.1.4 *Strand detensioning*—Detensioning should not begin until concrete has attained sufficient strength to resist compressive forces induced by the strand and the strand has bonded to the concrete in pretensioned construction. Strand transfer is normally undertaken when the concrete is at least 3000 psi (21 MPa) but varies with design. Each strand should be cut simultaneously and slowly at each end of the panel or prestressing bed. Detensioning should be performed in a manner to keep forces symmetrical about the panel vertical and horizontal axes.

6.4.2 *Reinforcement cage assemblies*—For information on detailing and placing reinforcing bars and welded-wire reinforcing, refer to ACI 318-11, ACI 315-99, the *Manual of Standard Practice* (CRSI 2003), and *Placing Reinforcing Bars* (CRSI 2005). Precast wall panel reinforcement is usually preassembled into rigid cages using a template or jig before the steel is placed in the form. Cage assemblies should be constructed to close tolerances, and the various pieces should be rigidly connected by tying or welding. When cages are tied, soft stainless steel or galvanized wire of at least 16 gauge (1 mm^2) is preferred. Reinforcement cages should be securely suspended from the back of the molds and held clear of any exposed surface. The suspension system should firmly hold the assembly in its proper position during concrete placing and consolidation. Permanent spacers or chairs supported on the form of an exposed concrete surface may mar the appearance of the precast panel. If possible, avoid using chairs. If used, spacers should be of a type and material that will not cause spalling of the concrete, rust marks, or other deleterious effects.

When concrete is placed, all reinforcement should be free of grease, oil, wax, dirt, paint, loose rust, mill scale, or other contaminants that may reduce bond between steel and concrete or stain the concrete surface. Reinforcing steel should not be bent after being embedded in fresh concrete.

6.4.2.1 *Welding of reinforcement*—Tack welding is only recommended for increased rigidity and should not be indiscriminately used. When absolutely necessary, welding should be done by certified welders with written approval of the engineer/architect and in accordance with the provisions of the American Welding Society (AWS D1.4:2005).

If epoxy-coated bars are to be welded, the coating should be removed by acid etching and rinsing the bar in clear water, or by mechanical means such as wire brushing, abrasive blasting, or grinding. All surfaces to be welded should be bright and clean. The clean area should be at least 1 in. (25 mm) larger than that which is to be welded on all sides of the weld. After welding, the reinforcement should be painted with epoxy coating to match original coating.

Welding galvanized reinforcement requires a special type of welding rod. Welding removes the zinc coating in the weld area. Because zinc fumes are toxic, adequate ventilation must be provided to remove fumes.

Small tack welds provide substantial stability to reinforcing bar cages but are not recommended for attachment to main reinforcement because steel crystallization (embrittlement or metallurgical notch) can occur. Tack welds that do not become a part of permanent welds of reinforcing steel are prohibited by AWS D1.4:2005, unless approved by the engineer. However, tack welding reinforcement at locations where bars do not have a structural function should be allowed. For example, welding the outside bar end within 10 bar diameters from the free end of the bar may aid in fabrication of reinforcing cages.

Reinforcing bars should not be welded within two bar diameters or a minimum of 2 to 3 in. (50 to 75 mm) from a cold bend, as this can result in unpredictable behavior of the reinforcing bar at the bend. Tack welding should be performed without significantly diminishing the effective steel area, or the reinforcing bar area should be one-third larger in area than required. Low heat should be used to reduce undercutting the effective steel area of the reinforcing bar.

Avoid welding higher-strength steels unless proper welding procedures are provided in writing. These procedures should identify the type of preheat and welding rods to be used. Welding should be prohibited near prestressing steel.

6.4.3 *Wythe connectors for insulated panels*

6.4.3.1 *Steel trusses, plates, and connectors*—Steel trusses should be installed per truss manufacturer's instructions. Typically, steel trusses are tied to the fascia wythe using welded-wire reinforcement, and concrete is placed in the bottom wythe. The truss is then raised or rotated to vertical position so two-thirds of the truss extends out of the concrete. Insulation is placed between vertical trusses. Any gaps are sealed with tape or caulk.

6.4.3.2 *Metal ties*—Typically, metal clips are C- or M-shaped and punched through the insulation before placing insulation atop the fascia wythe concrete. Concrete around the connectors should be compacted to provide good anchorage.

6.4.3.3 *High-strength FRP composite connectors*—While installing these connectors, follow manufacturer's instructions to ensure anchorage of the connectors in the concrete. Typically, insulation with predrilled holes is placed atop the fascia-wythe concrete and connectors are inserted in the predrilled holes. This should occur within 20 minutes of placing the fascia-wythe concrete. Concrete around the connectors should be consolidated to achieve proper anchorage of the connectors. Gaps larger than 1/8 in. (3 mm) between insulation sheets should be filled with spray foam to prevent concrete from entering the gap and creating a thermal bridge.

6.4.3.4 *Carbon fiber-reinforced polymer (CFRP) reinforcement*—Like steel trusses, carbon fiber trusses are installed between two side-by-side insulation sheets. CFRP shear trusses are precut to the desired length and width and inserted between insulation sheets. Care should be taken to install trusses at the correct depth to achieve proper embedment depth. Carbon fiber shear trusses can be stapled to the insulation edge at the correct depth before placing the insulation. Gaps larger than 1/8 in. (3 mm) between insulation sheets should be filled with spray foam to prevent concrete from entering the gap and creating a thermal bridge.

6.5—Concrete placement

6.5.1 *Transportation*—Concrete for casting precast wall panels is transported from the mixer and placed in forms by various methods, depending on the precasting operation layout or the panel type being manufactured. Many precasting plants have stationary mixers and deliver concrete to forms by buggies, buckets, conveyors, pumps, or other equipment. Some precasting plants operate from a controlled ready-mixed concrete plant and transport concrete by mixer trucks. Concrete truck delivery (ASTM C94/C94M-11) is often used for large volumes of concrete. In addition to speed and economy, avoiding segregation is a prime concern in transporting concrete. Before delivering a new batch of concrete, hardened concrete and foreign matter should be removed from the surfaces of the transportation equipment.

6.5.2 *Segregation*—The amount of segregation varies with the mixture consistency and aggregate grading. Secondary factors that may affect segregation are weather that affects consistency and the transportation mechanism. Equipment should be used that provides the least jarring and segregation from the time the concrete enters the transport carrier until it is delivered to the forms. Concrete should be discharged into forms while in its original mixed or plastic state without separation of coarse aggregate and paste.

6.5.3 *Consolidation*—Concrete used in wall panel manufacturing should be completely and uniformly consolidated by internal or external vibration, vibrating screed, impact, or a combination thereof. Although available consolidation systems vary widely, most are successful when properly applied. ACI 309R-05 and ACI 309.2R-98 present detailed recommendations for good consolidation practices and controlling surface defects.

Even concretes containing high-range water reducers should be consolidated by minimal vibration, unless concrete qualifies as SCC. Regardless of consolidation type, the goal is to avoid segregation and excessive bleeding while consolidating concrete into a dense, uniform mass with a surface as free of defects as practicable. Four typical vibration techniques are described hereafter. It is recommended that the consolidation method be left to the panel manufacturer as it depends on formwork, mixtures, and finish, among other factors.

6.5.3.1 *External vibration*—External vibration is usually achieved by mounting high-frequency vibrators directly to forms or by using a vibrating table. These vibrators operate at varying frequencies and amplitudes. Vibrating tables or forms should be sufficiently rigid to transmit vibration uniformly over the entire panel surface without any form damage. A vibrating table works best for flat or low-profile units. A degree of external vibration may be used to consolidate SCC but, generally, none is required.

6.5.3.2 *Drop-table vibration*—Drop-table vibration is used in some precasting plants to consolidate concrete with low total water content. The drop table will rise and fall an average of 3/8 in. (10 mm) at low frequency. Frequencies vary but are approximately 250 cycles per minute.

6.5.3.3 *Internal vibration*—Internal vibration is performed with a tamping-type motorized jitterbug or a spud vibrator. Spud vibrators should not be used to consolidate facing mixtures. Because backup mixtures are generally stiffer, they can be placed and vibrated in the same way that structural concrete is internally vibrated. Vibrators should not be allowed to contact interior form surfaces because contact may damage the form, mar the concrete surface, or drive coarse aggregate away from the form surface.

At times, a combination of external and internal vibration is required to properly consolidate concrete. When high-slump concrete is placed, segregation may occur. With normalweight concrete materials, coarse aggregate tends to settle to the bottom and fines rise to the top. With lightweight aggregates, the opposite occurs.

6.5.4 *Facing concrete*—Facing concrete should be carefully placed and worked into all parts of the form. This is particularly important in external and internal corners for true and sharp casting lines. Each batch of concrete should be placed as close as possible to its final position. The entire mass should be consolidated by vibration with as little lateral movement as possible. Face mixture thickness after consolidation should be at least 1 in. (25 mm) or 1.5 times the maximum size of aggregate, whichever is thicker. Facing concrete should be sufficiently thick to prevent any backup concrete from bleeding through and showing on the exposed face.

In deep returns, excessive air pockets are often created on the formed surface. These can generally be eliminated by rodding the concrete at the return surface with a thin, flat, spade-like tool after internally vibrating the concrete. Sequential casting, discussed in Section 6.6, is a technique that minimizes air pocket formation on the formed surface.

6.6—Surface finishes

6.6.1 *General methods*—Usually when a precast panel project reaches the fabrication stage, color and texture approval will have been set. Color and texture approval is generally accomplished by submitting a small sample, or in some cases a full-size unit, for approval by the engineer/architect. For structural panels, color is often not a requirement if project specifications call for the panel surface to be painted or stained.

Surface finishes can be achieved in many ways, depending on the desired architectural effect. Some surface treatments or finishes are executed when the concrete is plastic, whereas others are performed when the concrete has hardened. Finishes on fresh concrete generally use one of the following methods:

- Brooming, floating, or troweling the back face.
- Chemical surface retarders.
- Clay product veneer faces.
- Reveals made with rubber strips glued down or magnetically bonded to the steel form casting bed.
- Sand casting.
- Smooth metal form finish with field-applied color stains or paint.
- Special form finish.
- Stone veneer faces.
- Surface texturing using form liners.
- Thin brick placed in GFRP frames with concrete filling the joints.
- Water washing, brushing, or both.

Surface treatment of hardened concrete surfaces requires more labor and can be more susceptible to variations. Available methods include:

- Acid etching.
- Artificially created broken rib texture (hammered ribs or fractured fins).
- Bush-hammering or other mechanical tooling.
- Hand brushing, power rotary brushes, or both.
- Honing and polishing.
- Sand or other abrasive blasting.

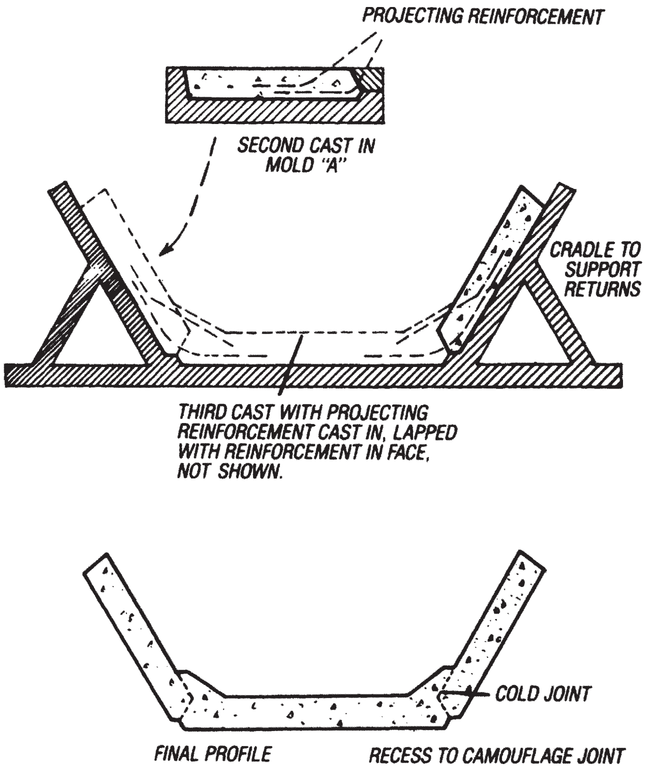
Refer to PCI MNL-122-07 for additional finishes and further discussion of finish treatments. Regardless of the type of finishing method, factors such as type and brand of portland cement, aggregates, compressive strengths (at time of final architectural finishing), and curing techniques used all affect final appearance. When finishes remove part of the concrete surface, the resulting panel should have adequate cover over the reinforcement to prevent corrosion and staining.

All finishing methods for a project should be studied before entering full fabrication. The precast manufacturer should develop quality requirements for all architectural finishes before undertaking fabrication of such finishes. The finishing process should produce an acceptable uniform appearance without loss of required concrete qualities. When two or more different mixtures or finishes are on the same panel, a demarcation (reveal) feature is necessary.

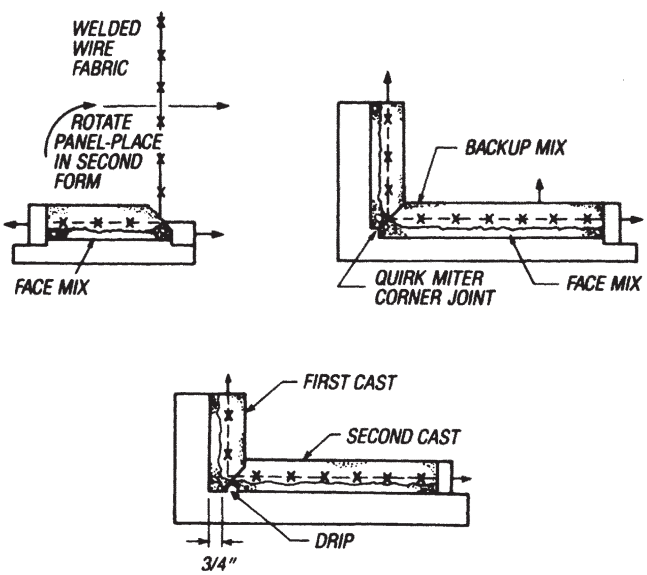
Panels with large or steep returns (such as channel column covers and some spandrels) may be cast in separate pieces to achieve matching high-quality finishes on all exposed faces and minimize air pockets. When these panels are joined, they are joined with dry joints as illustrated in Fig. 6.6.1. This casting method enables all panels to be cast face down with the same aggregate orientation and concrete density using conventional precast concrete forming methods. Back forming is then not required and a combination of face mixture and backup mixture can be used rather than 100 percent face mixture. When this fabrication method is indicated, attention should be paid to suitable corner details and reinforcement at the dry joints. Although the dry joint may not show with certain mixtures and textures, a groove will help mask the joint. Where desired, this joint can be recessed sufficiently deep to allow installation of a small backer rod and placement of a 1/4 in. (6 mm) bead of joint sealant (Fig. 6.6.1). Sometimes precautions are necessary to ensure watertightness of the dry joints.

6.6.2 *Chemical surface retarders*—Chemical surface retarders are available in varying concentrations to control the depth of aggregate exposure. They may be used to treat the finished exposed surface whether it is cast up or cast down on the bottom of the panel. Retarders considered for a project should be thoroughly evaluated under prevailing project conditions before fabrication. The retarder selected should be compatible with the particular type and source of cement, aggregates, and specific mixture selected for the panels. Surface retarder effectiveness varies when the heat of hydration of the cement is altered. The heat of hydration may be altered by larger concrete masses; precast product depth; changes in ambient temperature, humidity, or both; and by using insulated panels or changing cements.

6.6.2.1 *Applying retarder*—Chemical surface retarders are specialized chemicals that delay, but do not prevent, the set of the surface cement paste so that the concrete aggregate can be easily exposed. Form retarders are usually fast-drying, solvent-based materials designed to resist the abrasion inherent when placing concrete into forms coated



(a) separate casting stages of large retuns



(b) alternate casting positions

Fig. 6.6.1—Sequential precasting.

with a retarder. Retarders applied to the top surface of freshly placed concrete are usually water-based materials. Both retarder types have retardation strength formulated to produce different reveal depths. Usually after suitable testing, the one selected exposes 30 to 40 percent of the aggregate particle intended to be exposed at the surface.

Fig. 6.6.2.1—Aggregate exposed using surface retarders.

Retarders can be applied by roller, brush, or spray. Extreme care should be taken to ensure uniform application of the retarder to the mold or concrete surface.

Because the most suitable period for providing the final surface treatment may vary from 12 to 24 hours after casting, preliminary tests should be performed under job conditions before planning the casting for a large project. When removing the concrete matrix by water scrubbing or other mechanical processes, the exposing operation should begin immediately after stripping and before the matrix becomes excessively hard. Unformed surfaces may be treated at any time after initial set has taken place. Surface-retarded concrete is shown in Fig. 6.6.2.1.

6.6.3 *Abrasive blasting to expose aggregate*—Concrete age is not as critical for abrasive blasting as for other methods of exposing aggregates. Concrete should be less than 3 to 5 days old and all panels should have approximately the same compressive strength. Concrete mixture used, compressive strength at time of abrasive blasting, and the abrasive's grading and hardness all affect final exposure. Sand or abrasive blasting produces a muted or frosted effect that tends to lighten color and subdue aggregate luster. Nozzle diameter, air pressure, and type of abrasive should be determined by experimentation.

When sand is used as the abrasive, the effect of the sand's color on the panel should be reviewed. Certain combinations of blasting, sand grading, pressure, and volume can embed some blasting sand in the concrete surface. Because of this, blasting sand of similar color to the sand in the concrete matrix should be used. This situation can be minimized by changing the amount of material that hits the surface, changing the grading of the blasting abrasive and changing the pressure at the blasting nozzle. Once the blasting sand has been selected, the same sand and grading should be used throughout the project. Surface retarders used in conjunction with sandblasting can reduce sandblasting time and labor.

The surface of large flat panels should be separated into smaller sections with rustication strips or by using ribs and form liners to minimize the visual perception of textural differences.

Materials used for blasting operations include:

- Washed silica sand.

- Certain hard angular sands.
- Aluminum carbide.
- Blasting grit such as power-plant boiler slag.
- Carbonized hydrocarbon.
- Crushed chat.
- Organic grits such as ground nut hulls and corncobs.
- Deep exposure of coarse aggregate requires a finer gradation of sand abrasive to obtain uniform results. Trials of different abrasive materials with sample panels are made to check the texture and color tones. Sandblasted concrete having light to medium exposure is shown in Fig. 6.6.3.

Exposed aggregate finishes are popular because they are reasonably priced and provide a variety of appearances. This variety is achieved by varying the type, color, and size of aggregate, matrix color, exposure method, and exposure depth.

The different degrees of exposure are:

- *Light exposure*—Only the surface skin of cement and sand is removed to expose the edges of the closest coarse aggregate.
- *Medium exposure*—Cement and sand are removed so the coarse aggregate appears approximately equal in area to the matrix.
- *Deep exposure*—Cement and sand are removed from the surface so that coarse aggregate becomes the major surface feature.

The extent to which aggregates are exposed or revealed is largely determined by their size. Reveal should not be greater than one-third the average diameter of the coarse aggregate particles or one-half the diameter of the smallest coarse aggregate.

All sandblast operators should be protected with heavy gloves, aprons or protective clothing, and air-fed respiratory protection equipment. Due to environmental pollution compliance, use caution when selecting abrasive grits that produce very fine particles after impacting the surface. Different equipment may be required for wet blasting.

6.6.4 *Honing and polishing*—Honing and polishing provides a smooth, exposed-aggregate surface. Honing is generally performed by using grinding tools in stages, with successive degrees of grit fineness varying from approximately No. 24 (686 mm) coarse grit to a No. 300 (44 μm) fine grit. Polishing can be done with finer grits. Generally, honing alone provides a sufficiently smooth surface for precast panels.

Grinding elements are made with carborundum bonded by resin, or with diamonds set in grinding surfaces. Diamond elements cut faster and wear longer, but are initially more expensive. Honing and polishing equipment varies from hand grinders to elaborate multi-head machines. Air voids in the concrete surface should be filled with cementitious paste when the matrix is exposed during initial grinding. Thorough inspection is required to find and fill air voids after initial grinding. Subsequent grinding should be delayed until the fill paste material has gained adequate strength. Strength of the concrete and fill paste material should be 5000 psi (34.4 MPa) before beginning any grinding or polishing operations. Medium to deep exposures provide a more uniform

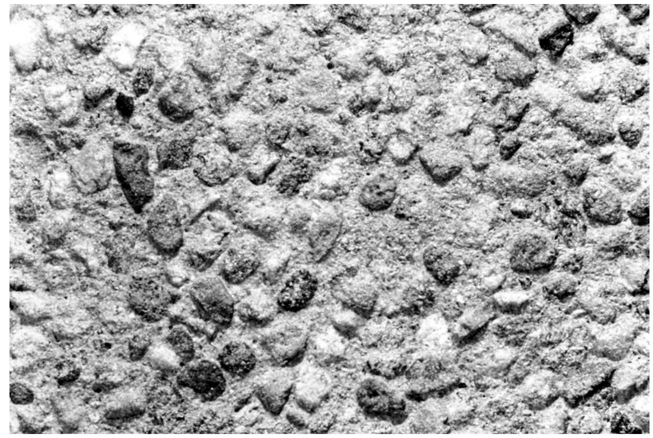


Fig. 6.6.3—Aggregate exposed by sandblasting.

appearance because coarse aggregates typically polish better than the concrete matrix.

6.6.5 *Acid etching*—Because many aggregate types are used in architectural concrete, caution is advised when using acids to expose aggregate. Before acid etching a concrete surface, the effects of various acid concentrations for exposing aggregates or cleaning panels should be thoroughly studied. Concrete aggregates should be quartz, granite, or other acid-resistant stone. Limestones, dolomites, and marbles will either dissolve or discolor when exposed to muriatic acid. Acids may also increase the chemical reaction between silicates in the aggregate and the free lime liberated from the cement. This can lead to calcium silicate deposits on the panel surface if residue hardens on the surface. Acid washes can damage the galvanizing of exposed hardware and reinforcing bars if cover is less than recommended.

When applying acid, it should be continuously brushed or scrubbed to ensure uniform reaction with the cement surface. Acid washing should not be performed until the concrete in the precast panel has reached a minimum strength of 3500 or 4000 psi (24.1 or 27.5 MPa). All personnel exposed to any acid from the surface application method should wear protective clothing and covering to prevent injury from acid spattering. Acid should be completely neutralized and flushed from the concrete with clear, clean water to prevent yellowing or other discoloration. The maximum time that acid should be allowed to remain on the concrete should not exceed 15 minutes. Deep etch exposure should be achieved by multiple treatments rather than prolonged contact.

6.7—Concrete curing

6.7.1 *Introduction*—Concrete cures provided that sufficient moisture is present and favorable temperatures are maintained. In precast concrete fabrication, initial curing usually takes place in the form. Secondary curing takes place after the product is removed from the form. Secondary curing may be less important in precast concrete because design strengths are established so panels resist maximum stresses usually occurring during stripping and handling. Concrete mixtures for precast panels generally contain Type III high-early-strength cement or very finely ground Type I cement with sufficiently high cement contents to assure adequate strength at stripping, usually 3000 psi (20.6 MPa). This strength is often achieved within 8 to 16 hours while the precast panel is still in the form. Panels with pretensioned prestressing or post-tensioning may require higher release strength and should be specified by the panel designer. Additional information on curing may be found in ACI 308R-01.

6.7.2 *Curing recommendations*—It is recommended that two different stages of curing be established for precast panels. The first 8 to 16 hours is the initial stage and the most crucial. Steps should be taken during this period to provide heat when necessary to maintain minimum temperatures and to prevent loss of moisture from the panel. Many long-line steel beds have built-in hot water pipes to provide radiant heating. The exposed portion of the fresh concrete in a wall panel should be covered during this initial phase.

After removal from the form, the secondary stage of curing will continue in an outdoor storage yard (when temperature permits) or enclosed building until final design strength has been reached. During this period, precast panels should be protected from excessive moisture evaporation and from temperatures below 50°F (10°C) to inhibit efflorescence.

It may be necessary to interrupt the secondary curing to examine the surface finish and perform any required patching. It cannot be overemphasized that curing at the early ages is extremely important to the strength and durability of the concrete panel.

6.7.3 *Curing techniques*—Any change in curing techniques during a given fabrication run may result in changes in color, texture, or uniformity of the wall panels. Therefore, curing procedures should be consistent and uniform from precast panel to precast panel as well as from day to day. Burlap and similar coverings may stain or discolor certain finishes and should be avoided. Because of their tendency to discolor, curing compounds should not be used except on the backside of panels before the removal of forms or on surfaces that will later receive a finish. Because some curing compounds and sealers may interfere with adhesion of surface coverings, coatings, and joint sealants, compatibility with these materials should be investigated.

6.7.3.1 *Curing temperature*—All curing of concrete should occur at temperatures above 50°F (10°C). When temperatures fall below this level during the first 16 hours, either external applied heat or heat retention measures are required. It should be remembered, however, that trial mixture proportions are usually prepared and tested at room temperatures of 70 to 75°F (21.1 to 23.9°C). When concrete is cured at lower temperatures, such as 50°F (10°C), concrete strength may be lower than laboratory tests indicated. When panel curing temperatures are expected to be lower than trial mixture temperatures, allowance should be made for slower strength gain and the early form stripping time should be adjusted accordingly.

6.7.3.2 *Steam curing*—Curing with steam simultaneously provides heat and moisture. Where steam curing is used, recommended procedures such as those of ACI 301-10 should be observed to achieve desired results. Steam should not be applied until after the initial set period of the particular concrete mixture. The initial set (delay) period should be determined by ASTM C403/C403M-08. The rate of temperature rise can be up to 36°F (20°C) per hour, provided a proper initial set delay period precedes the heating period (Pfeifer and Landgren 1982). Maximum temperature should not exceed 160°F (71.1°C). Cooling rates should also be controlled. Close control of steam curing procedures is required in connection with chemically retarded exposed aggregate surfaces. Steam curing can produce a greenhouse effect where moisture drips from the covering on to the panel and induces staining on the exposed panel surfaces (Greening and Landgren 1966).

6.7.3.3 *Curing in storage*—Strength gain can continue after panels are moved to the storage area. Take care to prevent rapid moisture loss when panels are placed in a storage yard. When ambient relative humidity is high, additional protection from rapid drying may not be required. In areas where hot, dry weather prevails, care should be taken to allow the panels to dry slowly.

Because concrete is saturated at early ages, new concrete is vulnerable to damage from even one freezing-and-thawing cycle until it reaches a nominal compressive strength of approximately 500 psi (3.4 MPa). At typical concrete strengths above 3000 psi (20.6 MPa), early freezing is not a problem and precast concrete panels may be immediately stored outside. However, panels of any strength will not be durable to repeated freezing and thawing unless adequate air entrainment is provided. Section 6.3.3 recommends that all concrete mixtures be air-entrained.

6.8—Storage

6.8.1 *General*—Because of the wide variation in precast panel sizes, shapes, and fabrication facilities, there are no standard methods of handling and storage. Precast panels temporarily stored in a general storage area should be supported at the blocking points designated on the installation drawings. Units should be stored in a vertical or near-vertical position. If stored in a horizontal or flat position, three dunnage points may be required depending on panel length. Handling and storage procedures should not cause structural damage, detrimental cracking, architectural impairment, or permanent distortion when the precast member is being:

- Lifted or stripped from the mold.
- Moved to various locations for further processing or storage.
- Turned into various positions to provide access for finishing, surfacing, or both.
- Stored before delivery.
- Loaded onto delivery vehicles.

6.8.2 *Protection*—During storage, the manufacturer should keep precast concrete panels in a clean, properly protected area to prevent staining. This does not mean the panels need to be in a covered area or should be covered. The need for protection depends on configuration of the units, length of storage time, and the local environment. To protect against freezing damage, inserts and other embedded items should be protected against water or snow penetration during cold weather. Storage should be planned carefully to ensure delivery and installation of the panels in an acceptable condition. Even though the panels may require washing after installation, protection may still be necessary against engine exhaust fumes or soil staining.

6.8.3 *Storage of thin flat panels*—Flat panels less than 4 in. (100 mm) thick or panels with a length-to-thickness ratio greater than 60 should be stored and shipped in a vertical or near-vertical position. Two-point supports spaced approximately at the fifth points are recommended for storage or lifting. Protective, resilient material should be provided at points of bearing and contact. All blocking, packing, and protective material should be clean and should not cause damage, staining, or disfigurement of the precast panels. Blocking and support members should be positioned and secured in a manner to prevent slippage, chipping at the chains, excessive binding, or excessive stresses. Avoid staggered or irregular blocking. Precast units should be stacked so they are supported on both sides to equalize loading and to avoid overturning.

Fig. 6.9—Delivery and transportation of panels.

6.9—Delivery

Most precast panels are delivered by semi-trailer trucks (Fig. 6.9). Some are shipped by rail, barge, or other modes of transportation. Precast plant facilities do not generally restrict the size and weight of precast panels that can be produced. However, shipping problems with oversize panels may greatly increase construction cost or delay project completion. Special transportation permits are generally required where height, width, or weight exceed specified limits. Using lightweight aggregate concrete panels can, in many cases, minimize the impact of weight in shipping, handling, and installation operations. Travel may be restricted to good weather, daylight hours, and weekdays. Lowboys or special trailers may be required for large or heavy panels. Greater economy can be achieved when large or heavy panels are shipped together on one trailer. Refer to Section 6.9.2 for information on economical panel sizes that can maximize trucking capacity.

All precast panels should be delivered to the site clearly marked as indicated on the installation drawings, with the fabrication date and an identifier showing final position of the unit on the structure. Precast panels should be selected from storage, loaded, and delivered in the proper order to meet the predetermined installation sequence.

Before scheduling equipment delivery, the erector should perform a field check of the project to ensure that the foundations, walls, and structure are suitably constructed to receive precast panel units. The site should be checked for crane and delivery truck access as well as possible field panel storage. Most panels should be loaded vertically and supported on A-frames mounted to flatbed trailers. They should be supported to minimize the effects of road shock and be securely fastened with all contact points protected from damage. Corners and returns of unusual lengths should be braced from edge to edge for greater protection in transit. All material that contacts the panel should be nonstaining.

If shipping panels horizontally, they should be supported at two points with the supports located at the fifth points of the long dimension to avoid excessive stresses that may be induced by twisting of the trailer, racking, or both. When the two-point support system is impractical, alternative support systems should be engineered and checked for feasibility relative to stresses and other potential problems.

6.9.1 *Protection during shipping*—Protective covering of a precast panel during delivery should be determined by the manufacturer after considering size and shape, finish type, aggregate type, transportation method, vehicle type, weather and road conditions, and distance of haul. Manufacturers are responsible for the condition of the delivered product, so they make the decision on wrapping unless the engineer/architect specifies a particular wrapping protection.

6.9.2 *Economical panel sizes*—Economical panel sizes depend on plant capability, distance from fabrication plant to job site, highway conditions, shipping, and installation restrictions. To maximize trucking capacity, panel design should consider height, width, length, and weight. Though it is common to ship two 12 ft (3.7 m) wide panels on a load, restrictions generally exist for loads wider than 8 ft 6 in. (2.6 m). Maximum permit widths can vary from 10 to 14 ft (3.1 to 4.3 m) depending on area. Some areas allow overall lengths over 70 ft (21.4 m) with a simple permit, front and rear escorts, and travel limited to certain times of day.

CHAPTER 7—INSTALLATION

7.1—Planning and preparation

7.1.1 *Coordination*—Early in the construction, before panel manufacture, the panel fabricator, erector, engineer/architect, owner, and the general contractor should hold a preconstruction conference.

Areas of concern that should be addressed during preconstruction planning are:

1. Determining site access, installation direction, and sequencing.
2. Identifying hazards.
3. Determining size and weight limitations.
4. Installation planning.
5. Selecting equipment. Using a tower crane with one line only may affect installation embedment location.

6. Developing an installation safety program.
7. Field layout and verification. Offset lines should be set at 2 ft (0.6 m) off the exterior around the perimeter of each floor.
8. Special handling requirements. Panels should be loaded so they can be lifted without damage.
9. Special lifting hardware.
10. Site storage availability.
11. Presurveying building connections before panel delivery.

This order indicates the usual sequence of activities, but many factors occur that influence project planning. Each step is further considered in this chapter.

7.1.2 *Responsibilities for precast installation*—The general contractor or construction manager (GC/CM) is normally responsible for project schedule, grid dimensions, and coordination with all construction trades. Relative to installation of precast concrete, the GC/CM, in conjunction with the precaster/erector, should:

- Be responsible for coordinating information necessary to produce precast concrete installation drawings.
- Maintain structure stability. When necessary, the precast engineer develops a bracing sequence to maintain structure stability during installation. This bracing sequence is developed in conjunction with the erector and engineer of record. Limitations may state, for example, that loading of the structure be balanced, requiring that no elevation be erected more than a stated number of levels ahead of remaining elevations. Other limitations may involve structure rigidity, requiring that walls not be erected before completion of floors designed to carry lateral loads.
- For steel frames, determine how far in advance of panel installation that final frame connections are to be completed. Particular consideration should be given to deflection and rotation of the supporting steel members due to the precast concrete and other superimposed loads. For concrete frames, the GC/CM should furnish to the erector strength of concrete and authorization to begin installation. The engineer of record should recognize that connections between panel and frame impose concentrated loads on the frame and that these loads may require supplemental reinforcement. For multistory concrete frames, consideration should be given to the effects of frame shortening due to shrinkage and creep.
- Review and obtain necessary approvals for all installation drawings and related design.
- Be responsible for coordinating dimensional interface between precast concrete and the work of other trades.
- Ensure that proper tolerances are maintained by other trades to guarantee accurate fit and overall conformity with precast installation drawings.
- Be responsible for providing and maintaining clear, level, well-drained unloading areas and road access around and into the structure so hauling and installation equipment can operate under their own power. Locate units to permit lifting by the installation equipment from trailers and placement directly into the structure.
- Establish installation sequences early and account for them in the bracing analysis and installation drawings. When a sequence is agreed upon, it should be strictly followed until conditions require a mutually agreeable change. Determine how many times the installation equipment should be moved to complete the work. On steel frames, consider the timing of application of fireproofing for prewelding that should occur. On concrete frames, location of formwork and any overhanging scaffolding can influence the method of installation and sequencing.

7.1.3 *Access*—Access conditions at the site should be reviewed, considering temporary roads for delivery trucks and handling equipment such as cranes. Responsibility for sidewalks, overhead lines, barricades, truck space at site, sequences, coordination with other trades, and panel protection should be discussed at a project coordination meeting. At this meeting, the precast erector should provide a scheme for handling, loading, transportation, and installation of the panels.

Temporary bracing of the structure, onsite storage, connections, starting location, and installation sequence relative to building stability should be discussed. At times, the direction of installation will be determined by gate entry points to the job site or location of construction trailers and storage facilities. The GC/CM should indicate where materials will be stored and man hoists will be located. Other job-site factors, including crane disassembly, will affect access and the direction of the work. Free and easy access to appropriate parts of the structure can often present the largest challenge to the erector. Site access should be a contract provision.

7.1.4 *Identifying hazards*—Careful review and inspection of the job site should be performed to identify obstructions that could limit equipment mobility. Overhead obstructions should be carefully considered in planning. Power lines may have to be moved or deactivated. Removal of tree limbs may be necessary.

All existing property to be protected, such as underground utilities, tanks, tunnels, trees, shrubs, existing asphalt, and concrete should be clearly identified. For projects close to airports, lights, flags, or both, may be required on booms.

7.1.5 *Project meetings*—During precast installation, the general contractor should conduct frequent project meetings between the erector and those subcontractors whose work is affected by the precast. These meetings help to ensure that all necessary provisions have been made to facilitate the installation process.

7.1.6 *Contract documents*—Contract documents should clearly state any requirements or sequencing of installations needed to maintain building stability. Limitations on loading of the structure, temporary bracing requirements, or elevation sequencing need to be clearly shown before bidding. All details of temporary installation bracing, temporary connections, and shoring should be reviewed by the engineer/architect. The removal sequence of any temporary installation connections should be shown because leaving these connections in place can result in structural behavior not intended by the engineer/architect.

7.1.7 *Preinstallation check*—Before starting installation, bearing walls, foundations, structural frame, bearing surfaces, notches, embedded plates, angles or bolts, and welded connections should be checked for dimension, location, line, and grade to ensure that the area to receive the precast panels is ready.

7.1.7.1 The GC/CM is responsible for establishing and maintaining, at convenient locations on the foundation or the building, control points, benchmarks, and lines in an undisturbed condition for use by the erector until final completion and acceptance of the project. If the building frame is not precast concrete, then benchmarks or building lines should be provided by the GC/CM in each area or at every level. Work points should also be provided for angled and curved building elevations.

7.1.7.2 The erector should be advised by the GC/CM of any known discrepancies in field location, line, or grade and be provided with suitable work areas for layout.

7.1.7.3 Before starting installation and scheduling delivery and lifting equipment, the erector should survey the project to check dimensional tolerances and anchor bolts that have been field-placed or are of contractor's hardware. The goal of this survey is to ensure that the areas to receive the precast concrete are ready and accessible to the erector and that the precast concrete units will fit. All dimensions and details taken should be checked against installation drawings. The precast erector should also spot check the access before scheduling the loading and handling equipment.

7.1.7.4 Layout is required before installation, so a starting point is clearly established and any possible tolerance conflicts with the support structure are determined early. Layout is required during installation to maintain proper alignment.

Layout before installation ensures that when an error is found, it can be corrected before starting installation. Any modification to bearing surfaces or connection hardware can be made by the general contractor before installation begins.

7.1.7.5 The erector should confirm that the minimum concrete strength has been achieved.

7.1.7.6 Notes of all discrepancies exceeding specified tolerances should be kept. Some discrepancies between site conditions and installation drawings that can cause problems during installation include structural steel out of alignment, anchor bolts or dowels improperly installed, errors in bearing elevation or location, and obstructions caused by other trades.

Such discrepancies should be noted in writing and sent, if appropriate, to the precast concrete manufacturer, GC/CM, or both. Installation should not proceed until discrepancies are corrected by the GC/CM, or until installation requirements are modified and reviewed by the engineer/architect. Verification of remedial work should be the responsibility of the GC/CM. The erector should return to the site for final layout verification after all necessary corrections of site conditions in the installation area have been made by the GC/CM and before installation starts.

Working from control points, benchmarks, and lines established by the GC/CM, the erector should establish offset lines and elevation marks, as required, for use at each floor level. It is the layout person's duty to mark the locations to receive the precast concrete units so the erector can place them with minimal measuring and moving to final position. The erector should maintain a checklist of items that have been shown to help expedite projects. Some of these items concern site conditions and relationships with the GC/CM and other trades. Others deal with the design of the product and connections. The erector's checklist should include at least the following:

- Verify availability of products.
- Check that installation drawings are easy to understand, properly cross referenced, and accurate.
- Suggest safe connections that allow quick release of the crane hook. This requires mechanical, bolted connections that allow positioning of the precast piece after the crane and any additional temporary connections are released.
- In cold climates, check for grouted connections that require special planning and procedures.
- Determine if loose hardware, installation materials, and bearing pads are available to be delivered to the job site.
- Prevent confusion by minimizing the number of different types of installation hardware. Make the designer aware of this important issue, particularly for those materials that vary only slightly.
- Compile area-by-area hardware breakdowns and summaries.
- Verify accurate placement of attachments in the structure.
- Verify that precast concrete is dimensionally correct and within tolerances. Plates, sleeves, inserts, and openings should be checked and cleaned.
- Review that connections are designed to industry standard tolerances and placed at convenient locations.
- Plan for the fewest pick points with one lifting device or as few different devices as practicable to avoid rigging changes.
- Whenever practicable, have units shipped in the orientation that they will be installed. Walls should be vertical, floor slabs horizontal, and properly positioned end-for-end. Some long members may need to be oriented on a truck in a particular manner because of site or rigging restrictions. If vertical pieces are too large and must be shipped flat, ensure that panels are designed so they can be rotated.
- Ensure that fall protection is designed into the structure, with tie-off eyes or inserts where needed. Holes in floor and roof members and openings in walls should be covered while in the precast concrete plant.

7.2—Unloading and handling

7.2.1 *General*—Panels should be loaded and delivered in the installation sequence established at project coordination meetings. Panels should be loaded so that they can be picked from the truck without damaging the panel. Panels should be lifted from delivery trucks and placed directly in their proper position on the building. This minimizes handling damage and is usually the most economical method. Many requirements in Chapter 6 concerning handling panels at the fabrication plant apply to job-site activity. Loading at the plant should also consider special conditions such as line availability if a tower crane is used for panel installation.

The precast erector should set out joint location and spacing before panel installation. This should minimize differential variation in panel joint width and identify problems caused when the building or adjacent materials are out of dimension or alignment.

7.2.2 *Delivery sequence*—A delivery sequence for panels should be flexible to allow for full loads, using reasonable fill-out units when necessary; control of unit position on the trailer with proper support for safety and economy; adequate advance notice of shipment; assurance of prompt unloading; and provision for on-site storage.

7.2.2.1 When possible, panels should be unloaded in a vertical position. This is usually the situation if single-story panels are shipped on frames in a vertical or upright position. Do not remove any chains, binders, or banding until the crane is hooked onto the precast element. Tie off all other panels to the trailer before picking a panel. All chains, binders, banding, protecting packing, and bracing should be carefully removed from around the panels. Comers and panels with returns of unusual length are shipped with special bracing, which should not be removed until the precast piece has been lifted slightly from the truck before installation. If belts are used in unloading, only one panel at a time should be removed. Protective material should be used between the belts and point of contact with the panel. Gangs of precast panels should not be removed with belt lifting devices unless the panels are palletized.

The exterior panel should always be unloaded first from a frame or a stack. Never slide a panel out from the middle of a stack. Maintain balance on the trailer during unloading by unloading alternate sides of the vehicle. Remaining adjacent panels on the trailer should be tied or blocked to prevent tipping.

7.2.2.2 After delivery, a panel may require rotation into a new position. For example, a tall panel delivered on its side should be rotated to a vertical position. A panel may also be delivered horizontal, lifted from the delivery vehicle, and up-righted in the air. The panel is normally rotated without being allowed to touch the ground. It may be necessary to bolt a support frame to the panel before rotating. Usually two lifting lines from the crane are used, although special rotating frames have been developed for use with one crane line.

7.2.3 *Lifting devices*—Lifting devices should be secured to panels in accordance with the lifting device manufacturer's recommendations. Thread bolts into inserts a minimum of 2.5 bolt diameters for coil inserts and a minimum of 1.5 bolt diameters for ferrule inserts to prevent stripping of the bolt or insert threads. At least two connections should be used whenever the panel is lifted so the panel or lifting line cannot spin and unscrew, causing the lifting line to become disconnected. Use bolts of a sufficient length to provide full embedment in the lifting device. Regardless of load requirements, a 1/2 in. (13 mm) bolt should be the minimum size used for handling any precast panel. Predrilled or self-drilled expansion bolts should not be used for handling or installation purposes. Occasionally, inserts, bolts, or other devices are provided only for the convenience of field handling. When these devices are located in finished edges or exposed surfaces, bolt and insert holes will require filling and repairing. When this is necessary, the engineer/architect should be advised so that the locations and repair procedure can be approved before panel fabrication. Repairs should be executed in accordance with Section 7.7. Always measure depth of the lifting insert and have several different length bolts available to ensure the bolt fully penetrates insert depth and not only the concrete.

7.2.3.1 One lifting device is a swiveling D-ring plate bolted to a threaded anchor. The swivel and bolt diameter should be the same size.

7.2.3.2 Coil-threaded anchors are discouraged when other anchor types can be used. Insufficient thread engagement is the most common problem with this system and it is dangerous if the bolt is not fully threaded into the anchor. When using coil-threaded anchors, the following precautions should be followed.

- It is imperative that thread engagement be a minimum of 2.5 times the nominal bolt diameter. Because anchors are sometimes recessed, the erector should locate the actual top of the steel anchor, as some threads may be concrete cover and not steel. When in doubt, the erector should scratch the threads with a metal object to verify anchor location.
- Caution should be used in tightening bolts, as they may break out the opposite face of a thin panel or may strip the insert threads.
- This anchor type is particularly affected by foreign materials such a sandblast grit, ice, or both, which can accumulate in the insert. Take care to remove foreign materials from inserts to ensure full thread engagement.
- A minimum of two coil inserts should be used to lift a unit so that the unit or lifting line cannot spin, causing the bolt to unscrew from the insert.
- Bolts of proper length should be used to prevent extensive shimming. Bolts that are too long may bend and fail.

7.2.3.3 The precast concrete manufacturer should be consulted regarding the design intent of all installation inserts. Connection hardware should not be used for lifting or handling, unless specifically designed and designated for this purpose on the installation drawings. Some precast members that are long, heavy, or both, may have sleeves through the member or anchors with swivel hardware for use in attaching installation hardware.

There are situations that require special lifting systems. These systems should be designed by a professional engineer and tested to verify the anchor will exceed a safety factor of 4-to-1 and the hardware 5-to-1. After selecting hoisting equipment, rigging should be sized to permit the precast concrete units to be lifted and installed safely.

7.2.3.4 Wire rope slings are usually the major component of the rigging assembly. Occasionally, web belts or chain mesh belts may be required. Hooks, shackles, rolling blocks, closed links, and lifting plates can be used with the slings to complete the system. All of these items are commercially available with test data to substantiate the safe working load for the available sizes of each product. Before using any of these items in a rigging assembly, it is imperative that the user consult the manufacturer's published charts and information to be aware of the conditions and limitations for which the safe working load data applies.

7.2.3.5 When rigging assembly components are custom-made, they should be designed by a professional engineer or experienced person with full knowledge of the range of intended use. Before a custom-made lifting apparatus is used as standard equipment, its capacity should be clearly labeled for future reference.

7.2.3.6 It is necessary that the erector receive accurate, individual unit weights and dimensions, and, if applicable, special handling requirements from the precast concrete manufacturer. Weight, handling requirements, and size of the unit to be lifted are critical for the erector to determine the rigging requirements.

7.3—Job-site storage

7.3.1 *General*—When scheduling requires job-site storage of precast panels, storage areas should be relatively level, firm, and well-drained. Storage areas should be located where there is little chance of damage due to other construction activity. Storage recommendations in Section 6.8 should be followed. Where long-term storage is necessary, panels should be covered to protect them from accumulation of dust, dirt, or other staining materials. Covers of canvas, rubberized sheets, heavy waterproof paper, GFRP sheeting, or other protective material should be considered.

7.3.1.1 The storage area may have to be stabilized so that differential settlement or twisting of the stored panel will not occur. Panels should not be stored on frozen ground without proper safeguards to prevent uneven settlement if the ground thaws.

7.3.1.2 It may be desirable to maintain an inventory of precast products on the project to prevent installation delays. This can be achieved by storing several loaded trailers on the job site. Leaving precast concrete members on the trailer is often the best solution for on-site storage. The trailer usually provides clean and safe storage and eliminates extra handling and possible damage. If a loaded trailer is stored at the job site, the shipper should stabilize the trailer to prevent tilting or overturning. This is important on frozen sites subject to thawing. The stored trailer should be parked on firm, level ground. Sufficient dunnage should be placed under the landing gear dollies to prevent them from sinking. This should be the responsibility of the erector only if the erector is responsible for transportation.

7.3.1.3 Site storage other than on trailers should be avoided, as it is expensive and can result in product damage. Unloading members directly from the delivery trailer to their final location on the structure without site storage is the preferred method. If a piece must ship out of sequence, the precaster should announce that a piece is coming out of order so the erector can plan for it. The erector has a few options:

1. The member can be installed in its correct location if the crane can reach it and if it does not interfere with installation of other units.

2. It can be stored temporarily on the ground, but this is often not preferred or practicable due to site constraints.

3. The piece can be left on the trailer or loaded onto another trailer.

Often, only the second option is available to the erector. Most job sites are congested. Finding an isolated location that is clear of debris and sufficiently level to allow safe storage is often difficult. When storing products on the ground, care should be exercised in determining that dunnage will support the unit without settling, warping, overturning, or damage. Softeners are always required both on the dunnage and at the points where a panel leans against a structure. Tall panels should be tied back to prevent overturning. When a panel is stored against a building, care should be taken to prevent damage to the building or the unit. The product should be protected against soiling or damage by other trades on the project. When on-site storage is for several pieces, storage areas should be level, firm, well-drained, and located where there is little chance of damage due to other construction activity. Any temporary storage at the job site should be planned to avoid overstressing the units. The area may have to be stabilized to prevent differential settlement or twisting of members. This is important for members stored by stacking. Units should not be stored on frozen ground without safeguards to prevent settlement when the ground thaws. Stacked units temporarily stored in an on-site storage area should be separated and supported at blocking points designated on the installation drawings. Dunnage should be arranged in vertical planes and sufficiently deep to provide clearance for lifting devices. Units should also be stored with identification marks visible.

When stacking stemmed members or planks, dunnage should not be higher than one stack of precast units. Members should be stacked so lifting devices will be accessible and undamaged. The upper members of a stacked tier should not be used as additional storage area for shorter members or equipment.

The erector is responsible for proper on-site storage, whether planned or unplanned. Once the erector inspects the material before unloading and accepts the material from the shipper, responsibility is assumed for safekeeping until the precast units are installed.

7.3.2 *Panel support*—Panels should be stored with identification marks clearly visible and supports at the blocking points shown on the installation drawings. Panels should be blocked to prevent tipping. When panels are placed against a frame or support, they should be set on protective material laid horizontally under and between the panels. This protective material should be selected so that the blocking material will not stain the panels. Plastic chairs, chain guards, and bearing pads are readily available and do not stain. Wood blocking should be wrapped in GFRP sheeting to avoid wood stains that can cause panel rejection. Polystyrene blocking may dissolve when sealer solvents contact it. This leaves an unsightly patch of polystyrene that is difficult to remove without defacing the panel. When solvent-based sealers are not used, polystyrene provides good protection if it is adequately sized to support the imposed load.

7.4—Installation

7.4.1 *Workmanship*—Workers should be trained to handle and erect precast concrete panels. Installation methods should be planned to avoid soiling, cracking, chipping, and damage to built-in items. Chipping and spalling may be repaired at the job site after installation, when performed to the satisfaction of the engineer/architect.

7.4.1.1 Installation supervisors are not generally expected to know how to operate the equipment they supervise. They should, however, be familiar with the proper setup, limitations, and safe use of the equipment. They should obtain the operator's inspection report before giving instructions to proceed with the work.

7.4.1.2—Safe and efficient use of cranes, hoists, personnel lifts, and other specialized equipment requires operator training and qualification. The erector should have competent and careful operators that are trained in handling the loads and the safe operation of the specific equipment they will be expected to operate. Serious hazards can result from improper hoisting operations or using equipment for a purpose for which it is not intended or designed.

The equipment operator should have knowledge and understanding of equipment operating characteristics, capabilities, and limitations, including equipment-rated capacity and effect of variables on capacity, safety features, required operating procedures, and skill in manipulation and control of equipment through all phases of operation.

7.4.2 *Equipment*—Handling equipment for precast panel installation should be safe and reliable under all anticipated conditions. It should accomplish handling and installation quickly and economically and minimize any potential hazard to on-site personnel, nearby public, or property. A job analysis should be conducted to select the most appropriate installation equipment and best site locations from which the most panels can be safely handled without equipment movement. When selecting equipment, it is necessary to ensure that it will be safe, reliable, and in good working order in all anticipated conditions to which it will be exposed and operated. Factors involved in equipment selection include the following:

- *Mobility and cost*—Availability and cost of the handling equipment, cost of altering boom length or other modifications, mobility for anticipated site conditions, and whether the panels will be walked or carried.
- *Capacity required*—Weights, dimensions, and lift radius of the heaviest and largest precast panel; maximum lift height, radius, and the weight to be handled at that elevation; number and frequency of lifts.
- *Clearance needs*—Clearance between load and adequate headroom in which to operate, ground clearance and conditions of the ground on which to set the equipment, and overhead clearance of wires and adjacent buildings.

7.4.2.1 Equipment selected should meet or exceed all project requirements and have a minimum 5 percent working margin of reserve load capacity on every lift for unanticipated problems. When slings are used for panel installation, the included angle between the sling lines should never exceed 90 degrees (or 45 degrees from the vertical). All wire ropes for hoisting equipment should be sized for the load picked. They should also be maintained and not kinked.

7.4.2.2 Check lifting devices to assure that their capacity and intended use conforms to the manufacturer's recommendations. Panels should be handled only at the locations and with the hardware shown on the installation shop drawings. If slings are used, the panel should be marked so the slings are placed in the proper location.

7.4.2.3 The following considerations should be evaluated when turning, rotating, or tripping precast units in the air using both the main line and auxiliary (whip) line:

- • Verify that whip line has sufficient pull. Remember that it may initially carry more than half the unit weight.
- • Verify that the crane is capable of multi-parting the whip line as well as the main load line.

Consideration should be given to restraining the load from spinning while lifting with two lines. If the main and auxiliary lines go over adjacent sheaves so that the lines are side by side, the piece will also try to orient itself to match. It is important to be ready for this possibility.

7.4.3 *Bracing and guying*—Bracing requirements should be established before bidding so that proper allowances can be made. Necessary bracing and guying material should be delivered to the job site before installation begins. All bracing and guying methods should be designed to support all construction loads including wind. Building design should provide for structural stability during installation of the precast panels. Because structural stability may not be achieved until proper alignment and final connections are made, bracing may be required.

When bracing or guying is used, the manufacturer's recommendations should be followed regarding load, length, and inclined angle. Location, size, and capacity of the insert in both the panel and floor slab is important. A brace or guy should never be connected to a precast panel at a point lower than two-thirds of the panel height. Temporary bracing or guying should be arranged so that it does not interfere with other panels being erected. Removing one brace should not remove support from the remaining panels. Temporary bracing or guying should not be removed until building stability has been achieved through other means or until authorized by the engineer/architect.

7.4.4 *Safety*—The erector should develop a written safety program that is committed to workplace safety and providing the structure for achieving a zero-accident culture. Workers should be provided with the appropriate personal protective equipment.

7.4.4.1 All supervisors should be trained to recognize and correct hazards and to identify and respond to unsafe behavior. Training should focus on prevention through planning and emphasize the importance of the supervisor's role in safety. This will include the regulatory obligation for them to recognize and control job-site hazards. It will also underscore the significance that direct and indirect costs can have on their company's financial results. To prevent accidents, workers should be trained in practices and procedures and rules and regulations, and be motivated to work safely. Employees should sign and date an acknowledgment sheet verifying that they have received, read, and understand company safety policies. Employee training programs should be designed to ensure that all employees understand and are aware of the hazards to which they may be exposed and the proper methods for avoiding such hazards.

7.4.4.2 Job-site safety meetings should be held at the beginning of a project to ensure workers are familiar with company safety policies, anticipated hazards, safe job procedures, and requirements of the upcoming installation work, including the Installation Safety Plan. Indoctrination of new employees and long-term employees new to the job site is particularly important. In addition, installation crew safety meetings, such as toolbox meetings, should be conducted weekly to discuss topics designed to increase worker safety. These meetings should be documented as to attendance and subject matter, and all employees should be required to attend.

Upon project commencement, employees should be made familiar with the following:

- Identity of first aid representative.
- Location of job site telephones for emergencies.
- Location of emergency phone numbers and addresses of nearby doctors, ambulance services, hospital, and police and fire departments when 911 service is not available.
- First aid equipment.
- Bloodborne pathogens exposure control plan.
- Location and proper use of fire extinguishers.

7.4.4.3 The safety program should require that all accidents resulting in injury to workers, damage to equipment or product, or both, regardless of their nature, be investigated and reported. Near misses should also be reported and investigated. It is an integral part of every safety program that documentation be completed immediately so that the cause and means of prevention is identified to prevent recurrence. In addition, when an accident results from an employee's failure to follow job procedures, this should be reviewed with all employees performing the job.

7.4.5 *Alignment*—Offset lines are generally marked on the floors for multistory buildings or on foundations for single-story buildings. Precast panel elevations are generally established by setting the properly sized shim pack on the floor or beam. Shim material should have a bearing capacity of approximately 1000 psi (7 MPa). Each panel should be erected to meet the tolerances in Chapter 4. To maintain overall building dimensions, it is necessary to work to joint centerlines, permitting joint widths to vary. If a joint size is detailed as 1/2 in. (13 mm) and the panel tolerance is 1/4 in. (6 mm), the joint may vary from 3/4 to 1/4 in. (19 to 6 mm), provided approved connection and installation procedures are followed.

7.4.6 *Connections*—Connections should be compatible with both precast and supporting frame tolerances, simple in detail, and easily adjusted in the field to meet project conditions. Connections should allow for installation independent of ambient temperature without temporary protection measures. They should be as standardized as practicable to minimize plant and field installation quality control problems. Once agreed upon by the engineer/architect, erector, and precast supplier, the connections selected should be shown on the shop drawings submitted before panel fabrication.

7.4.6.1 *Bolted connections*—Connections should be designed so that members can be safely secured to the structure rapidly without completing alignment and all adjustments. Bolted connections are positive immediately and allow for adjustment without requiring large handling equipment. Care should be taken during adjustment to prevent damage to the panels or the adjacent building materials.

Standardized attachment hardware such as clip angles, blots, and shims help minimize errors and control inventory. Regardless of the load requirements, a 1/2 in. (13 mm) diameter bolt should be the minimum size used. Clip angles should be slotted or have oversized holes to allow for product tolerances and building movement.

7.4.6.2 *Welded connections*—Where welded connections are required, welding should be in accordance with AWS D1.1/D1.1M:2010 and the installation drawings. These drawings should show the type; size; length of weld; sequence; minimum preheat; interpass temperature; weld location; and, where critical, the electrode type. Panels may be shimmed during initial tack welding. Bracing or other provisions should safely hold the panel in position while the handling equipment is released and adjacent panels are placed.

Before temporary bracing is released, the designated full weld should be in place at every connection in the precast panel. To minimize staining, all loose slag and debris should be removed immediately after welding is complete. Panel finish and surrounding materials may require protection from sparks and smoke stain. Noncombustible shields should be used to protect exposed concrete surfaces during welding.

7.4.6.3 *Post-tensioned connections*—Vertical post-tensioning, horizontal post-tensioning, or both, may be used for field connection of precast panels using either bonded or unbonded tendons. Bonded tendons are installed in preformed voids or ducts. They are made monolithically with the member and protected from corrosion by grouting after the stressing operation is completed. Grout should fill all voids in and around the entire tendon length. Unbonded tendons are connected to the precast panel only through the anchorage hardware. Anchorage devices for all post-tensioning systems should be aligned with the direction of the axis of the tendon at the point of attachment. Concrete surfaces against which the anchorage devices bear should be in the plane of the tendon and normal to the tendon direction. Post-tensioning operations require qualified personnel experienced with the stressing procedures and equipment to be used.

7.4.6.4 *Dowels and grouting*—Strength of a dowel connection in tension or shear depends on the embedded length and the developed bond. Because placement of a portland cement grout or epoxy grout is required during installation, using dowel connections usually slows installation and may be costly.

For doweled or grouted connections, setting shims are located and grout holes are filled just before setting precast panels. The concrete in and adjacent to the grout holes should be damp or in a saturated surface-dry condition. Grout consistency should permit displacement of some grout when panels are positioned. Where grout beds are required, panels may be set on shims and later dry-packed with mortar. Panels may also be set on fresh grout with the elevation controlled by shims. Excess grout should be removed if it interferes with other construction activities. Avoid using epoxy and cementitious grouted connections when the ambient temperature is below 40°F (4°C). Mixing and installing epoxy grouts should be in strict accordance to the manufacturer's instructions. In selecting doweling and grouting methods, consideration should be given to how the final joint will be made and how the corners will be joined. Adjusting the precast panel after the initial set of the grout can destroy the grout bond and reduce connection strength. Doweled and grouted connections should only be used as part of the structural design concept. Doweled and grouted connections should not be used unless embedded and welded connections are impractical. Generally, doweled and grouted connections cannot be used December through April in cold climates.

7.5—Tolerances

7.5.1 The precast concrete manufacturer and erector are responsible for meeting specific tolerances in the fabrication and installation processes, respectively. The engineer/architect should coordinate the tolerances for precast concrete work with the requirements of other trades whose work adjoins the precast concrete construction. In all cases, tolerances should be reasonable and within generally accepted limits. It is recommended that the designer review proposed tolerances with precasters and erectors before deciding on final project tolerances. In turn, the precast manufacturer, GC/CM, and erector should carefully monitor tolerances to construct the structure as designed. Tolerances are divided into three categories:

- 1. Product tolerances (Section 4.5).
- 2. Installation tolerances (Sections 4.6 and 4.7.2).
- 3. Interface tolerances (Sections 4.7 and 7.5.3).

7.5.2 The erector should notify the precast manufacturer immediately when out-of-tolerance products prevent proper connection or fitting so that corrective action can be taken for the remaining fabrication. When a product cannot be erected within the tolerances assumed in the connection design, the erector should notify the precaster and GC/CM to check the structural adequacy of the installation. The connection design should be modified, if required.

No product should be left in an unsafe condition. Any adjustments affecting structural performance, other than adjustments within prescribed tolerances, should be made only after approval by the precast design engineer. Products should not be forced into place or installed by any method that would induce or impose any undue stress or overload on the structure, on the products, or on the connections. Any deviations should be reported to the precast manufacturer.

7.5.3 Interface tolerances and clearances are those required for joining different building elements in contact with or in proximity to the precast concrete and to accommodate relative movements expected between such elements during the life of the building. Typical examples are tolerances for window and door openings, reglets, mechanical and electrical equipment, elevators, stairs, walls, and partitions. Tolerances should closely match typical fabrication tolerances for the materials to be joined plus an appropriate clearance for differential volume changes between materials. Fabrication and installation tolerances of other building elements should be considered in design. Precast concrete units should be coordinated with and accommodate the other structural and functional elements compromising the total structure. Unusual requirements or allowances for interface should be stated in the contract documents.

7.5.4 Cracks and major damage occurring during installation should be noted and reported to the precast engineer by the erector.

7.6—Cleaning

Panels delivered to the job site should be clean and in acceptable condition. The erector should recoat all welds and abraded steel with rust inhibitor or, in cases of galvanized plates, with a cold galvanizing coating to prevent rusting, which can stain the panels. Generally, the erector is responsible for any chipping, spalling, cracking, and other damage to the precast panels after delivery to the job site and during installation.

The general contractor assumes responsibility for panel protection after panel installation. The general contractor should also make arrangements to provide protection for adjacent materials such as glass and aluminum that may be damaged by weld splatter or other construction materials such as fireproofing. Otherwise, adjacent materials should not be installed until panels are in place, repaired, and cleaned.

Any mortar, grout, plaster, stains, or other matter on the panels during general construction should be immediately washed off with clean water or cleaned as otherwise required. Rainwater or water from construction hoses can wash across building materials and cause discoloration of exposed precast panels.

7.6.1 *Cleaning procedures*—When cleaning exposed panel faces, they should be washed with a cleansing agent mixed with hot water and thoroughly rinsed with clear water. A good fiber brush should be used for cleaning. Panels are usually cleaned from top of the building downward. Individual precast panels are cleaned from the bottom up. After washing from bottom to the top, panels should be rinsed and washed from top to bottom, followed by a second rinse with clear water.

Do not allow cleaning solutions to dry on concrete surfaces that will be exposed to view. Final finish should be sound with exposed concrete free of all laitance, dirt, stains, smears, or other blemishes.

7.6.2 *Stubborn stains*—When stains remain after cleaning with a stiff brush and cleansing agent, the panel surface should be thoroughly wetted with clear water and then scrubbed with a dilute solution of muriatic (hydrochloric) acid. This solution concentration may be increased to a maximum of 5 percent muriatic acid, but try weaker solutions first. A thorough washing with clear water should immediately follow scrubbing. Honed and polished surfaces cannot be acid cleaned where there are soluble aggregates such as limestone or marble on the panel face. Acid cleaning may change the appearance of sandblasted surfaces. Take care to prevent damage to adjacent material corrodible by the acid. Glass and aluminum trim are susceptible during acid scrubbing and washing. Repeated applications of a cleaning acid on the exposed surface of the precast panel may change panel texture or color. The effect on appearance may necessitate extensive washing of all project panels. Commercial cleaners may be desirable instead of acid. Because muriatic acid may leave yellow stains on white concrete, a 3 to 5 percent phosphoric acid solution may be preferred on white or very light colored concrete panels. Workers using cleaning compounds or acid solutions should be trained in their use. The use of proper protective wear should be strictly enforced. Rubber gloves, glasses, and other protective clothing should be worn by workers using acid solutions or strong detergents. Materials for chemical cleaning can be corrosive and toxic. All precautions on labels should be observed because these cleaning agents can affect eyes, skin, and lungs. Materials that can produce noxious or flammable fumes should not be used in confined spaces unless adequate ventilation is provided.

7.6.2.1 *Sandblasting and steam cleaning*—Dry or wet abrasive blasting, using sand or other abrasives, may be considered if this method was originally used in exposing the unit surface. Steam cleaning may also be used to clean panels. The architectural precaster or an experienced subcontractor should perform any sandblasting. A venturi-type nozzle should be used for its solid blast pattern, rather than a straight bore nozzle that produces light fringe areas. Sandblasting can dull aggregate or change color or texture so that it no longer matches the structure. A small area, preferably on the mockup panel, should be tried and approved before proceeding with work.

7.6.2.2 Stone veneer-faced precast concrete units should be cleaned with a stiff fiber, stainless steel, or bronze wire brush; a mild soap powder or detergent; and clean water using high pressure, if necessary. Acid or other strong chemicals that can damage or stain veneer should not be used. Information should be obtained from stone suppliers on methods of removing oil, rust, and dirt stains from the stone.

7.6.2.3 Mortar stains can be removed from brick panels by thoroughly wetting the panel and scrubbing with a stiff fiber brush and a masonry cleaning solution. A prepared cleaning compound is recommended; however, on red brick, a weak solution of muriatic acid and water (not to exceed a 10 percent muriatic acid solution) may be used. Acid should be flushed from the panel with large amounts of clean water within 5 to 10 minutes of application. Buff, gray, or brown brick should be cleaned in accordance with the brick manufacturer's recommendations, possibly using proprietary cleaners rather than acid to prevent green or yellow vanadium stains and brown manganese stains.

Following application of the cleaning solution, the panel should be rinsed thoroughly with clean water. High-pressure water cleaning techniques using 1000 to 2000 psi (6.9 to 13.8 MPa) washes may also be used to remove mortar stains.

7.6.2.4 Unglazed tile or terra-cotta surfaces should be cleaned with a 5 percent solution of sulfuric acid for gray or white joints, and a more dilute (2 percent) solution for colored joints. The surface should be rinsed with clean water both before and after cleaning. Glazed tile manufacturers generally do not recommend using acid for cleaning.

7.6.2.5 *Cleaning sealed panels*—If panels that have been sealed before shipping to the site require cleaning, it may be necessary to remove the sealer and recoat the panel after cleaning. Surface sealers should never be reapplied until all cleaning and repairs are complete. For information on removing specific stains from concrete, refer to PCA (1988).

7.7—Patching and repairing

7.7.1 *General*—Minor chipping of precast panels during transportation and handling at the job site can be expected. Damaged panels can be repaired after installation, but major spalls or cracks require an engineering evaluation. Repairs require expert craftsmanship for the panels to be both structurally sound and pleasing in appearance. Careful planning is required to determine that repairs can aesthetically match existing surface concrete both in color and texture and be structurally sound. In some cases, it is more feasible to recast the panel. All patching and repairs should be fully cured, cleaned, and dry before sealing joints between panels. Refer to ACI 546R-04 for general guidelines for concrete repair. Repairs should conform to contract documents and be architecturally satisfactory. Gross variations in color and texture of repairs from adjacent surfaces may cause rejection and a request for panel replacement.

7.7.2 *Written repair procedures*—The precaster should prepare a written repair procedure that clearly defines when to consult the precast engineer to determine an appropriate repair. Major repairs should not be attempted until an engineering evaluation determines whether or not the unit is structurally sound. When repairable, the precast engineer should approve the procedure.

Selecting techniques or materials for repair depend on the extent of damage, product function, availability of equipment and skilled manpower, economic considerations, requirement for speed of repair, and importance of appearance. It is important that all repairs are performed in advance of final cleaning and joint sealing. Any repair work on joints should be fully cured, clean, and dry before caulking. All repairs and remedial work should be documented and kept in job record files.

7.7.3 *Determining when to repair*—Evaluate imperfections in the concrete to determine if repairs should be attempted. Repairs can accentuate flaws rather than remove them. Slight color variations between the repaired area and original surface can occur due to the different age and curing conditions of the repair. Several weeks, or possibly months, will normally blend the repair with the surrounding area so that it becomes less noticeable. Repairs should be performed only when conditions ensure that the repaired area will conform to the surrounding work with respect to appearance, structural adequacy, and durability. Hand tool surface blemishes before undertaking patch repairs. Needle scaling, bushhammering, or other mechanical tooling can effectively blend offsets or variations in color and texture.

7.7.4 *Developing repair mixture*—Use the job-site mockup or a damaged reject panel to develop a patch mixture design and practice repair and texture techniques. In most cases, it is better to complete preparation of all finishes on the precast panel before beginning any patching or repairs. Recent repair areas can be damaged when repairs are made ahead of the panel finishing. Patch mixture designs and finishing techniques should be documented so new workers can take over repairs if initial restoration specialists leave the project.

7.7.5 *Chips and spalls*—Chips, spalls, and areas of unsound concrete may be prepared with a hand-held or pneumatic chisel. The repair area should be chipped to a depth 1.5 times the maximum size of aggregate to assist in holding the patch mixture in place.

When repairing chips or spalls, all loose material should be removed using a hand-held or pneumatic chipping hammer. Areas should be cut back, usually 1 to 2 in. (25 to 50 mm) until coarse aggregate breaks, rather than loosens, under chipping. The side of the hole should be vertical or slightly undercut to provide a key at the edge of the repair. Depth of area to be repaired should be at least 1.5 times the maximum aggregate size. Very thin edges (feather edges) should not be permitted and cutouts should be at least 3/4 in. (20 mm) deep to provide a shoulder of sufficient depth to permit a smooth finish. For exposed aggregate finishes, cutting back the concrete in an irregular pattern minimizes detection of the repaired area. In liner-type finishes, it may be desirable to cut back along the texture lines to obscure repair location. All dust should be brushed or blown from repair area. The entire repair area, as well as adjacent surfaces, should be prewetted before applying a recommended bonding agent. A stiff predesigned patch mixture should be applied onto repair area and compacted by dry-tamping for maximum density.

Large repair areas need coarse aggregate in the patch mixture or the aggregate should be hand placed and rodded into the patching grout. Strike the repair area level and add any surface texturing while the concrete is still fresh. Begin curing immediately. If the spalled-out piece of concrete is available and fracture surfaces still mate, the easiest repair is to put the spalled concrete back into place using epoxy adhesive. Both the fractured surface of the panel and spalled piece should be painted with the epoxy adhesive. Apply sufficient epoxy so that some epoxy squeezes out when the mated pieces are clamped together. Use an epoxy with sufficient viscosity to prevent sagging or running on vertical surfaces. It may be necessary to drill through the spalled piece and into the precast panel to set pins or bars to increase anchorage.

7.7.6 *Smooth finishes*—Disguising a repair on smooth finish is difficult because of variations in color and texture, particularly if dark cements are used. Color differences in dark concrete are more noticeable than in lighter-colored concrete. Obtain a smooth surface by wiping the repair with cheese cloth or a similar material, rubbing with carborundum stone, or by grinding. A light abrasive blast with very fine silica blasting sand may remove the dark color. This abrasive blast is applied using a suction-fed sandblasting pot with a trigger-type nozzle at 40 psi (0.26 MPa) maximum pressure. Sandblast approximately 28 days after applying the repair. When there are numerous surface air voids, it may be desirable to simulate them with the point of a nail before initial set of the repair concrete.

7.7.7 *Formliner finishes*—In cases where liner texture was applied, it may be necessary to use a liner to impress onto the repair the desired texture as the concrete sets. The compacted repair should be struck flush with the original surface. A small section of formliner that has been attached to a board or wooden float should be pressed against the repair while the repair mixture is plastic. When practicable, the liner should remain in place to help with curing. Where the surface is board-marked, texture can be carried across a repair by striking off the surface with a straightedge held parallel to the direction of the marks. When the surface is ribbed, it may be necessary to form the rib and fill the form with the repair mixture. Rib lengths should be varied so that a straight line pattern does not extend across the ribs.

7.7.8 *Exposed aggregate finishes*—For exposed aggregate finishes, after compacted repairs are struck flush with the existing surface, damp coarse aggregate should be hand-placed into the mixture, if not already added in the repair mixture. Coarse aggregate should be patted into the surface with a small wooden block. Use a wood or rubber float to cover the aggregate with the repair mixture. After initial set of the repair mixture, use stiff nylon bristle brushes and water to expose aggregate and texture the finish to blend with the surrounding concrete. A wet paint brush or soft natural sponge can also be used to achieve the desired texture. Sponging the repair surface after texturing can effectively remove cement laitance and may eliminate the need for further cleaning. Take care so as not to roll the aggregate and damage the fresh repair mixture material.

7.7.9 *Sandblasted finishes*—To obtain a sandblasted finish, cure the repair for 5 to 7 days, then lightly sandblast using a suction-fed sandblast pot with a trigger-type nozzle at 30 to 60 psi (0.21 to 0.41 MPa) pressure, depending on exposure depth. A fine-graded silica blasting sand, 120 to 200 mesh size (12.5 to 75 mm) should be used. A conventional sandblaster with a 3/8 to 3/4 in. (10 to 19 mm) diameter venturi nozzle may also be used, provided that a pressure valve in the air line maintains pressure at the desired range. Another method to obtain a deep sandblasted finish is to cure the repair for 7 days then use a deep blast on the repair, filling in with the proper matrix and then lightly brushing to proper depth before initial set.

In some cases, aggregate may be sandblasted before use in the mixture. This abrades and dulls the aggregate surfaces and allows the surfaces of the exposed aggregate in the original to match the surrounding surface.

7.7.10 *Honed or polished surfaces*—If honed or polished surfaces need repair, the repair should be built up 1/8 to 3/16 in. (3 to 5 mm) higher than the surrounding finished face then ground flush using hand tools of successively finer stone until the specified finish, level, and planeness are achieved. Small chips should be repaired using a tinted epoxy containing crushed and graded coarse aggregate fines to minimize paste volume. Twenty-four hours after application, hand-polish repairs to match the surrounding concrete.

7.7.11 *Curing of repairs*—Adequate curing methods for repairs should be implemented immediately to ensure that the repair does not dry too quickly and cause it to shrink away from the existing concrete. The repair area should be moist-cured for at least 3 days, but 7 days is preferred. Moist curing can be accomplished by covering with a blanket of damp flannel, linen, cheese cloth, or other nonstaining fabric and a cover of polyethylene taped or tied to the concrete. Exercise care to avoid washing or eroding the repair. If needed during curing, additional water should be added to the fabric and the GFRP covering replaced. The curing method should be tested on trial repairs made in the mockup sample unit. Nonstaining membrane curing compounds may be sprayed over a repair and later removed by scrubbing with soap and water or by acid washing if the unit was originally treated with acid. Heat lamps that maintain a temperature in the repair of between 50 and 75°F (10 and 24°C) are recommended for curing in cold weather.

7.7.12 *Blending color differential*—Chemical treatment can sometimes improve color differential between units. Bleaches, acid, acid-and-water combinations using a pressure gun, or acrylic or silane sealers with toners can be used in chemical treatment. Concrete discoloration can sometimes be corrected by bleaching darker areas and using pigmented sealer to blend the area with the surrounding concrete. Light-colored areas can also be treated with a pigmented sealer. Oxidizing agents that may be used include:

- Commercial sodium or potassium hypochlorite solutions such as liquid household bleach;
- A 10% solution of phosphoric or oxalic acid;
- A 20 to 30% water solution of diammonium citrate;
- One part sodium citrate in six parts of lukewarm water mixed thoroughly with seven parts lime-free glycerol (glycerine); or
- One part ammonium or sodium citrate in six parts of lukewarm water.

These solutions should be applied to the surface and to a blanket of flannel, linen, or cheesecloth that is then placed over the surface and covered with polyethylene. Application should be made on a mockup panel or small samples before use on finished architectural panels.

7.7.13 *Crack repair*—Panels may crack during transportation and installation. Structural and visual acceptability of cracks should be determined by the engineer/architect and owner. Refer to Section 3.5.3.1 for information on crack acceptability. The repair method for a crack depends on its size, location, and the engineering problems causing the crack. Cracks that are nonworking or have no significant structural problems may be chipped or routed out and repaired in the same way as chips and spalls (Section 7.7.3). When cracks have occurred and repairs are required, aesthetic cracks that range from 0.002 to 0.25 in. (0.05 to 4 mm) wide can be repaired by pressure injection of low-viscosity, high-modulus, 100-percent-solid, two-component epoxy conforming to ASTM C881/C881M-10. Type, grade, and class should be chosen to satisfy job conditions and requirements. The system should be capable of bonding wet surfaces unless it can be assured that the crack is completely dry. Exercise care to select an epoxy color that closely matches the concrete surface. Epoxy-filled crack repairs should be done before sandblasting, if applicable. Blasting before epoxy work will cause the crack to have rounded edges, and it will be more difficult to minimize the crack appearance.

Small cracks equal to or less than 0.010 in. (0.26 mm) wide may not need repair, unless failure to do so can cause reinforcement corrosion in severe environments. If repair is required for the restoration of structural integrity, cracks may be pressure injected with low-viscosity epoxy. The epoxy should be capable of bonding to a moist surface because it is usually impossible to remove moisture in the crack. This approach can be used on all cracks wider than approximately 0.002 in. (0.050 mm). Epoxy injection depends on concrete temperature and viscosity of the epoxy. A typical epoxy repair procedure is detailed in the following:

- Thoroughly clean the cracked area.
- Drill entry port holes along the crack one-half the thickness of the precast panel and space entry ports along the crack at intervals approximately equal to the panel thickness.
- Provide a temporary surface seal with wax, grout, hydraulic cement, or epoxy resin sealant.
- Inject low-viscosity, 100-percent-solid epoxy into ports beginning with the lowest port. A pressure of 90 psi (0.62 MPa) is usually recommended.
- Continue to inject at lowest port until epoxy flows from the next highest port along the crack.
- Plug each injector port after it has been filled.

Continue the procedure until the entire crack has been filled. After the epoxy cures, remove the temporary surface seals, ports, and extra epoxy. Surface texturizing or sandblasting the repaired concrete area is necessary to remove all traces of epoxy or the surface seal coat. Refer to ACI 503.1-92 for detailed information.

CHAPTER 8—QUALITY REQUIREMENTS AND TESTS

8.1—Introduction

8.1.1 *General*—An effective quality assurance and quality control program (QA/QC) in precast panel fabrication benefits the precaster by reducing the cost of repairing or remaking products due to fabrication errors. Quality control also reduces the chance of structural failure due to reinforcing bars being omitted or mislocated. Precast erectors benefit when panels meet tolerances because they do not spend extra time looking for satisfactory ways to erect out-of-tolerance panels. Owners benefit when a structure is received that meets the requirements within the agreed-upon budget. The main objective of a QA/QC program is to provide comprehensive fabrication inspection and testing so that panels conform to project specifications.

8.1.2 *Incoming materials*—The QA/QC program should review the specifications and identify those specification sections for incoming materials. Specifications should clearly identify the tests or inspections to be performed or other means or methods to be used to determine material acceptability. These may include analysis certificates, mill test reports, and compliance certificates. Inspection records should be kept for a minimum of 2 years or as called for in the project documents.

8.1.3 *In-process QA/QC*—QA/QC programs can simplify and improve the interrelation among owner, engineer/architect, contractor, and panel fabricator. In such programs, forms, reinforcement, and embedments should be inspected before concrete placement. The face finish of the panel should be inspected after the panel is cured and stripped from the form. Before shipping, the finish surface of the panels should be inspected for compliance with project requirements for color uniformity and texture. Inspection procedures should be designed so that panel fabrication proceeds as scheduled with minimum delay. A good QC program is simple and consistent. It describes the product and includes specifications, fabrication tolerances, and assembly drawings. It should also detail packaging, storing, and shipping information. Complicated plant procedures and controls lead to uncertainty and confusion.

8.1.4 *Product finish*—There is always variation in the color, texture, and finish from panel to panel. Acceptable panels should show no obvious surface defects, other than minor color and texture variations, when seen in good typical lighting at a distance of 20 ft (6 m). Final appearance of the product is difficult to evaluate because it is subject to the personal interpretation of the engineer/architect or owner. Where there is a great concern about the color, texture, or uniformity of the panel, the owner should require mockup panels or samples as recommended in Section 1.4. Once the owner or engineer/architect has inspected the samples and selected an acceptable range of finish and texture, the inspector has a tangible standard for reference.

8.1.5 *Nonconforming materials*—The QA/QC program should specify how nonconforming materials (incoming materials, in-process materials, and finished products) are segregated from conforming materials until a decision is made about how to dispose of or rework the nonconforming materials.

8.2—Unacceptable defects

Cracks can usually be repaired. The precast fabricator should have an opportunity to make repairs before any panels are rejected. The following list gives definitions of unacceptable panel defects that should not remain on the finished panels.

- *Casting defects*—Excessive surface air voids on the exposed surface, casting lines evident from different placements and poor consolidation, areas of backup concrete bleeding through the facing concrete, foreign material embedded in the panel face, reinforcement shadow lines.
- *Stains*—Rust or other stains, blocking stains or acid stains evident on the exposed surface.
- *Irregularities*—Ragged or irregular edges, visible form joints or irregular surfaces.
- *Nonuniform color and texture*—Panels not matching the approved samples for uniformity of color within a panel or from panel to panel, nonuniformity of aggregate color, adjacent flat and return surfaces with greater difference in exposure than the approved samples.
- *Cracks and repairs*—Cracks or repairs visible at 30 ft (9 m) after final installation and finish.

8.3—Structural adequacy

Precast panels should be inspected to assure they are structurally sound. When the inspector finds cracks, chips, or spalls in a panel and is unsure of their impact, he/she should refer the problem to the engineer/architect so that the condition can be evaluated. Even though repairs may be structural, all repairs should match the surrounding concrete and meet architectural requirements.

8.4—Prestressing

Prestressing procedures are described in Section 6.4.1. The strand should be kept untangled and free of any material that affects bond to concrete. Strand chucks should be clean, lubricated, and crack-free. Hydraulic jacks with gauging systems are normally used for strand tensioning. Gauge readings and elongation measurements should be taken and recorded for each strand being stressed. The gauges, which should be accurate to within 2 percent of the applied pressure, should be calibrated at least once a year, or whenever the accuracy of the jack load is questioned.

8.5—Materials

8.5.1 *General*—Panel materials should be continuously evaluated to assure they meet their respective specifications. In some cases, the material evaluation program involves only obtaining and reviewing mill or material supplier reports. However, in other situations, it may include extensive testing.

8.5.2 *Reinforcing steel*—Reinforcing steel should be checked to see if it is the proper size and grade. If the reinforcing steel is to be used as an anchor for welded embedment assemblies, the carbon equivalent should meet AWS D.1.4:2005 requirements. Reinforcing steel should meet the requirements of ASTM A615/A615M-09, A706/A706M-09, or A996/A996M-09.

8.5.3 *Welded assemblies*—Welded embedment assemblies should be inspected to ensure they are fabricated with the correct size plates and number of anchors. Welding procedures should be monitored to ensure that welds have adequate strengths.

8.5.4 *Concrete*—In many instances, concrete for precast wall panels is batched at the site of panel fabrication because special cements and aggregates are used. The control and testing of this concrete is the responsibility of the precaster and should be identified in the QA/QC program.

8.5.4.1 *Cement*—Cement should be evaluated for its strength-producing characteristics. The cement supplier should provide a certified mill test report with each shipment and also data as outlined in ASTM C150/C150M-11. Mill test reports should be kept for at least 2 years. It is beneficial to obtain a 10 lb (4.5 kg) sample from each delivery and store it in an air-tight container for future evaluation in case strength or color problems occur.

8.5.4.2 *Aggregates*—Normalweight coarse aggregates and fine aggregates should meet the requirements of ASTM C33/C33M-11, except for gradation of aggregates used in the face mixture. Structural lightweight aggregates should meet the requirements of ASTM C330/C330M-09. All aggregates should be sampled in accordance with ASTM D75/D75M-09, tested for grading in accordance with ASTM C136-06, and for specific gravity in accordance with ASTM C128-07. Aggregate tests should be made for every 200 yd^3 (153 m^3) of concrete produced, but not less often than once every 2 weeks.

8.5.4.3 *Admixtures*—Admixtures should meet the following specifications as appropriate:

- ASTM C1116/C1116M-10 for nonmetallic fibers.
- ASTM C618-08 or C1240-11 for pozzolans and mineral admixtures.
- ASTM C260/C260M-10 for air-entraining admixtures.
- ASTM C494/C494M-11 or ASTM C1017/C1017M-07 for chemical admixtures.

Chemical admixture materials should be evaluated in the laboratory or in trial batches in the field to assure compatibility with the cement used in the concrete. If the admixtures are to be used in architectural precast concrete, they should be evaluated for their effect on the concrete color and color consistency.

8.5.4.4 *Mixing water*—If the water comes from a municipal water system, it may be used in concrete without further testing. If the water comes from an unqualified source, it should be tested for use in concrete by obtaining a chemical analysis and by making 2 in. (50 mm) mortar cubes as described in ASTM C109/C109M-11. Baseline data should be obtained using a proven water source. If the 7-day compressive strengths of concrete made with the unproven water source equal 90 percent of the companion control, the water is satisfactory for use in concrete.

8.5.4.5 *Pigments*—The pigment supplier should certify that pigments or other coloring agents are resistant to lime and other alkalis and conform to ASTM C979/C979M-10. A simple test can be made by mixing 20 parts of cement with one part of the pigment, using sufficient water to form a smooth paste. Samples should be kept moist and observed for several days. If considerable fading occurs, the pigments are unsuitable. Under these test conditions, it is possible for the test samples to develop efflorescence. The efflorescence should be removed with dilute muriatic acid or 5 percent phosphoric acid followed by copious washing with water before the true color can be evaluated. Testing color durability under the influence of light can be a lengthy process and sometimes a special artificial light is used to accelerate aging. Pronounced fading of a colored mortar upon exposure to sunlight for 1 month is evidence that a pigment is unsuitable.

8.6—Testing fresh concrete

8.6.1 *Consistency*—Concrete consistency should be tested at least once per day for each mixture used. Significant variation in consistency usually indicates variations in air content from batch to batch, or a change in aggregate moisture content, grading, or density. Two common methods for measuring concrete consistency are the slump test and the Vebe consistometer.

8.6.1.1 *Slump*—The slump test quickly and easily provides reliable information about concrete consistency. ASTM C143/C143M-10 provides detailed instructions on the proper test procedure. A tolerance up to 1 in. (25 mm) greater than the maximum specified slump may be allowed for individual batches, provided the slump variation does not affect the appearance or other concrete qualities beyond specification limits. Concrete of lower-than-usual slump may be used, provided that it can be properly placed and consolidated.

8.6.1.2 *Consistometer*—The Vebe consistometer subjects concrete to a slump test on a vibrating table (ACI 211.3R-02). Concrete consistency is measured in the time, in seconds, required to consolidate the slump cone mass into a 9-3/8 in. (238 mm) diameter mass. Concretes requiring a Vebe time greater than 6-1/2 seconds may be difficult to properly consolidate with internal vibration. Concretes with Vebe times less than 4-1/2 seconds have excellent consolidation characteristics.

8.6.2 *Air content*—The air content of air-entrained concrete should be tested at least once a day for each mixture design whenever strength test specimens are made. An air content check should also be made when any of the following changes occur:

- Slump varies more than ± 1 in. (25 mm).
- Concrete temperature varies more than ±10°F (–12°C).
- Finishing difficulties develop.
- Bleeding appears or increases.
- Aggregate grading changes significantly.
- There is a change in concrete mixture design yield.

8.6.3 *Unit weight*—Unit weight tests of backup concrete should be performed at least once per week for each mixture design used regularly, except for lightweight concrete, which should be tested daily. When air content tests are made, it is usually easy to also determine the GFRP unit weight of the concrete.

8.6.4 *Temperature*—Fresh concrete temperature should be recorded whenever strength specimens are cast. In addition, concrete temperatures should be recorded at the start of operations each day and at frequent intervals in hot or cold weather. An armored thermometer accurate to ±2°F (–17°C) should remain in the sample until the reading stabilizes.

8.7—Testing hardened concrete

8.7.1 *General*—Concrete mixtures should meet the durability specifications and achieve the compressive strength criteria outlined in ACI 318-08, Chapter 4. Generally, precast concrete develops strength in excess of the requirements for in-place loads. These higher compressive strengths allow earlier stripping for form reuse, better architectural finishes, and crack resistance during handling and installation.

8.7.2 *Durability*—Due to the vertical orientation of most panels, critical saturation is seldom reached and resistance to freezing and thawing has rarely been a major problem. When precast concrete panels require durability tests, they should follow the procedures of ASTM C666/C666M-03(2008). A minimum allowable durability factor of 70 is recommended. Air entrainment is recommended for panels subject to freezing-and-thawing conditions, but a specified fixed air content level is not recommended (refer to Section 5.5.2).

8.7.3 *Absorption*—A water absorption test of the proposed facing mixture can provide early indication of weathering or potential staining properties of the concrete. For the concrete strengths typically specified for architectural precast concrete, reasonable water absorption should not be a problem unless cement-rich or high-water-cementitious material ratio mixtures, or both, are used.

8.7.3.1 *Procedure for absorption tests*—Specimens should be tested after the concrete is 28 days old. Specimens should be oven-dried between 180 and 225°F (82 and 107°C) until the weight loss in 24 hours is less than 0.1 percent. Test samples should be cooled to room temperature, weighed, and then submerged in water to one-half the specimen height. After 24 hours, they should be submerged in water until the water is flush with the specimen top. In both cases, the water should be maintained between 65 and 75°F (18 and 24°C). After another 24 hours, the specimens should be removed, the surface water wiped off with a damp cloth, and specimens weighed on a scale having a resolution of 0.003 oz (0.1 g). Percentage absorption is the difference between wet weight and oven-dry weight, divided by dry weight, and multiplied by 100. This value may be transformed to volume percentage based on the unit weight of the concrete tested. Maximum water absorption for normalweight concrete face mixtures should not exceed 14 percent by volume. Specimens should be clean and free of parting agent, form release agent, or sealer. Take care not to mix any of these agents into the concrete.

8.7.4 *Test specimens*—Confusion and discrepancies often exist in selecting the size and shape of test specimens. Many precast plants prefer 4 x 8 in. or 6 x 12 in. (100 x 200 mm or 150 x 300 mm) cylinders. Others prefer 4 in. (100 mm) or 6 in. (150 mm) cubes for evaluating absorption and compressive strength. Generally, the 4 x 8 in. (100 x 200 mm) cylinder and the 4 in. (100 mm) cube are not used when maximum aggregate size in the concrete mixture is greater than 1 in. (25 mm). Test specimens should be consolidated, cured, and finished similarly to the products they represent.

8.7.5 *Molds*—Molds for making test specimens should comply with applicable requirements of ASTM C31/C31M-10 and C470/C470M-09. Heavy gauge, reusable steel molds, rather than single-use molds of paper, lightweight metal, or GFRP are preferred. Any molds that become distorted or do not comply with the dimensional requirements of the appropriate ASTM specification should be discarded.

8.7.6 *Compressive strength test specimens*

8.7.6.1 *Test cylinders*—Samples for strength tests should be taken on a strictly random basis as specified by ASTM C172-10. If choice of sampling times or the concrete batches to be sampled are selected on the basis of appearance, convenience, or other biased criteria, statistical concepts lose validity. No more than one test should be taken from a single batch and water should not be added after the sample is taken.

Four compression specimens should be made daily for each individual concrete mixture (whether facing or backup mixture), or for each 40 yd^3 (30.6 m^3) of any one mixture when daily consumption exceeds this volume. Two specimens should be used to determine stripping strength, particularly if the mixture is new and its history not well known. However, one specimen may be sufficient as fabrication progresses. For face mixtures, specimens typically required for determining stripping strength may be omitted when air temperature is higher than 50°F (10°C).

Test specimens should be made and stored as near as practicable to the location where they will be cured in accordance with ASTM C31/C31M-10. Consolidation and finishing procedures should follow ASTM C31/C31M-10 and C192-07 requirements.

Capping procedures should be as specified in ASTM C617/C617M-11 except when fast-setting, high-strength sulfur compounds specially manufactured for capping are used. Compression testing may be performed after the recommended cure time for the capping compound.

8.7.6.2 *Cube test specimens*—Most of the requirements of Section 8.7.6.1 can be applied directly to cube preparation and testing. Slight deviations will be required in concrete consolidation as a result of different specimen size and shape. When using cubes, it is reasonable to place the concrete in a single 4 in. (100 mm) layer for the 4 in. (100 mm) cube and two 3 in. (75 mm) layers for a 6 in. (150 mm) cube. Perform tamping or external vibration in accordance with ASTM C31/C31M-10. Similar to restrictions for 4 in. (100 mm) cylinders, internal vibration should not be used to consolidate either cube size.

Measured compressive strength for cubes is generally higher than that obtained with concrete cylinders made from the same concrete. Cube data should be correlated to standard 6 x 12 in. (150 x 300 mm) test cylinders if cubes are to be consistently used as the quality control specimen. If no correlation is available, 80 percent of the measured cube strength should be used as an estimate of the strength of the same concrete when tested using cylinders.

8.7.6.3 *Curing considerations*—When fabricating precast panels, initial curing of the concrete usually takes place in the forms. A test specimen should be cured with and by the same method as the unit it represents up to the time that the product is stripped from the form or mold. When the precast panel is to be steam cured, the test specimen mold should withstand elevated temperature without significant distortion.

When the precast panels are removed from their forms, the test specimens should also be removed from their molds and placed in a continuous moist condition at 73.4 ± 3°F (23°C ± 1.5°C). This is the secondary curing stage. An alternative method for secondary curing may provide the best measure of potential strength of a particular concrete mixture. The alternative method calls for at least 2 days of continuous moist curing after removing specimens from the molds, followed by storage at approximately 50 percent relative humidity until the sample is tested. Because this is not an ASTM-designated procedure, it should be considered only after the engineer/architect evaluates ambient weather conditions for the project area.

8.7.7 *Tests of finished panels*—When questions arise about adequate strength of a panel or series of panels, the quality of the concrete can best be established by core tests. Alternative methods such as rebound hammer, pullout tests, and penetration probe tests have been used along with pulse velocity testing. Depending on the problem, some equipment and procedures may be better than others in determining the strength of the concrete in the panel.

8.7.7.1 *Core tests*—In the past, acceptance tests for compressive strength have been limited to taking cores. Test cores should always be prepared, conditioned, tested, and reported in accordance with the requirements of ASTM C42/C42M-11. The average strength of three representative cores should be at least 85 percent of the specified strength. No single core should be less than 75 percent of that specified. Core sample length-to-diameter ratio should be as close to 2:1 as possible. Any core showing evidence of damage before testing should not be tested and should be replaced with another core sample.

The engineer/architect should select the location for drilling cores where they will least impair the structure strength and the exposed surface finish. Core holes can often be patched without damage to the appearance or integrity of a precast panel. When practicable, cores should be drilled so that the core test load is applied in the same direction as the service load. Often, top drilling of core samples minimizes or eliminates damage to the panel face. Because most architectural precast panels are cast flat, top coring of the panel produces a representative sample of concrete. Cores taken perpendicular to the panel face may be up to 15 percent weaker than cores taken parallel to the panel face.

Drill cores with a diamond bit to avoid an irregular cross section and damage from drilling. When a core sample is broken, wooden wedges should be used to minimize the likelihood of damage. Allow an extra 2 in. (50 mm) of core length at the broken end to permit sawing off ends to plane surfaces before capping.

8.7.7.2 *Rebound hammer*—Rebound hammer tests should not be used as acceptance tests for precast panels, but they are valuable for qualitative comparisons at the plant for the same job. The rebound hammer test, conducted in accordance with ASTM C805/C805M-08, can be used to locate areas of lower strength concrete or to track day-to-day variations in the fabrication concrete strength.

8.7.7.3 *Pullout tests*—The pullout test, as described in ASTM C900-06, provides a direct indication of the tensile strength of in-place concrete. This test involves drilling into hardened concrete and installing an expansion anchor or embedding an anchor disc during casting of the concrete. The expansion anchor or embedded anchor disc is pulled out perpendicular to the concrete surface, bringing with it a truncated cone of concrete. A relationship between pullout force and compressive strength of the concrete can be developed for a particular project by means of laboratory tests. Good data correlation between field and laboratory compression tests is required for this test to give valid results. These tests are typically done on the back of the precast panel where minimum repair is needed.

8.7.7.4 *Penetration probe*—The penetration probe test, conducted according to ASTM C803/C803M-03, is relatively nondestructive, reasonably accurate, and economical. However, an established relationship between compressive strength and probe test results should be developed for each of the different concrete mixtures used in the precast panels. Once the background comparison testing on concrete cores and cylinders has been performed, the probe test can provide reliable results. Because the amount of penetration is inversely proportional to concrete strength, a reading of concrete compressive strength is immediately obtained. Each probe leaves only a small hole that can be easily filled with an epoxy patching compound.

8.7.7.5 *Pulse velocity*—The principle of the ultrasonic test (ASTM C597-09) is that the velocity of longitudinal ultrasonic pulses traveling in solid concrete depends on the density and the elastic properties of the concrete. The test is not a substitute for other methods of evaluating compressive strength, but it is a good method for detecting cracks and cavities; for examining panel damage due to frost, fire, or chemical attack; and for assessing the relative general quality of concrete. The test requires access to both sides of the panel. Its use for approximating in-place concrete strength by nondestructive means is limited to those cases where concrete is sufficiently strong to allow pulse transmission at velocities greater than 11,500 ft/s (3.5 km/s). Correlations have been established between pulse velocity and concrete properties such as density, static modulus of elasticity, and dynamic modulus of elasticity. The measured pulse velocity is an average velocity if the facing and backup concrete are significantly different.

8.8—Documentation

Record keeping is an essential part of any quality control program. Management should establish, distribute, and update operational procedures for record keeping so that every person employed in the precasting operation knows what documentation is required. Documentation need not be elaborate; it may require completion of an outline or a simple data form, but it is integral to implementing quality control through control of materials, control of concrete mixtures, control of fabrication, control of handling, and control of technical services.

Precasters should develop a rational system of analyzing fabrication test results and keeping records on materials, breakage, damage, and rejection or rework. Data concerning inspection and test results should be recorded and reviewed, particularly when evaluating new materials and products. Record keeping should identify the characteristics of all precast panels with a specific mark number that can be tied to a certain mold or form on a specific date.

CHAPTER 9—REFERENCES

American Concrete Institute

117-10

Specifications for Tolerances for Concrete Construction and Materials and Commentary

211.1-91
Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete
211.2-98
Standard Practice for Selecting Proportions for Structural Lightweight Concrete
211.3R-02
Guide for Selecting Proportions for No-Slump Concrete
212.3R-10
Chemical Admixtures for Concrete
222R-01
Protection of Metals in Concrete Against Corrosion
224R-01
Control of Cracking in Concrete Structures
224.1R-07
Causes, Evaluation, and Repair of Cracks in Concrete Structures
301-10
Specifications for Structural Concrete
304R-00
Guide for Measuring, Mixing, Transporting, and Placing Concrete
308R-01
Guide to Curing Concrete
309R-05
Guide for Consolidation of Concrete
309.2R-98
Identification and Control of Visible Effects of Consolidation on Formed Concrete Surfaces
315-99
Details and Detailing of Concrete Reinforcement
318-08
Building Code Requirements for Structural Concrete and Commentary
440R-07
Report on Fiber Reinforced Polymer (FRP) Reinforcement for Concrete Structures
440.6-08
Specification for Carbon and Glass Fiber-Reinforced Polymer Bar Materials for Concrete Reinforcement
503.1-92
Standard Specification for Bonding Hardened Concrete, Steel, Wood, Brick, and Other Materials to Hardened Concrete with a Multi-Component Epoxy Adhesive
546R-04
Concrete Repair Guide
551.1R-05
Tilt-Up Concrete Construction Guide
ITG-7-09
Specification for Tolerances for Precast Concrete

ASTM International
A108-07
Standard Specification for Steel Bar, Carbon and Alloy, Cold-Finished
A153/A153M-09
Standard Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware
A185/A185M-07
Standard Specification for Steel Welded Wire Reinforcement, Plain, for Concrete
A276-10
Standard Specification for Stainless Steel Bars and Shapes
A307-10
Standard Specification for Carbon Steel Bolts and Studs, 60 000 PSI Tensile Strength
A325-10
Standard Specification for Structural Bolts, Steel, Heat Treated, 120/105 ksi Minimum Tensile Strength
A416/A416M-10
Standard Specification for Steel Strand, Uncoated Seven-Wire for Prestressed Concrete
A421/A421M-10
Standard Specification for Uncoated Stress-Relieved Steel Wire for Prestressed Concrete
A490-10
Standard Specification for Structural Bolts, Alloy Steel, Heat Treated, 150 ksi Minimum Tensile Strength
A496/A496M-07
Standard Specification for Steel Wire, Deformed, for Concrete Reinforcement
A497/A497M-07
Standard Specification for Steel Welded Wire Reinforcement, Deformed, for Concrete
A615/A615M-09
Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement
A706/A706M-09
Standard Specification for Low-Alloy Steel Deformed and Plain Bars for Concrete Reinforcement
A722/A722M-07
Standard Specification for Uncoated High-Strength Steel Bars for Prestressing Concrete
A767/A767M-09
Standard Specification for Zinc-Coated (Galvanized) Steel Bars for Concrete Reinforcement
A775/A775M-07
Standard Specification for Epoxy-Coated Steel Reinforcing Bars
A884/A884M-06
Standard Specification for Epoxy-Coated Steel Wire and Welded Wire Reinforcement
A996/996M-09
Standard Specification for Rail-Steel and Axle-Steel Deformed Bars for Concrete Reinforcement
C31/C31M-10
Standard Practice for Making and Curing Concrete Test Specimens in the Field
C33/C33M-11
Standard Specification for Concrete Aggregates

C42/C42M-11
Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete
C94/C94M-11
Standard Specification for Ready-Mixed Concrete
C109/C109M-11
Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens)
C128-07
Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Fine Aggregate
C136-06
Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates
C143/C143M-10
Standard Test Method for Slump of Hydraulic Cement Concrete
C150/C150M-11
Standard Specification for Portland Cement
C172-10
Standard Practice for Sampling Freshly Mixed Concrete
C185-08
Standard Test Method for Air Content of Hydraulic Cement Mortar
C192-07
Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory
C227-10
Standard Test Method for Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar-Bar Method)
C260/C260M-10
Standard Specification for Air-Entraining Admixtures for Concrete
C289-07
Standard Test Method for Potential Alkali-Silica Reactivity of Aggregates (Chemical Method)
C330/C330M-09
Standard Specification for Lightweight Aggregates for Structural Concrete
C403/C403M-08
Standard Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance
C470/C470M-09
Standard Specification for Molds for Forming Concrete Test Cylinders Vertically
C494/C494M-11
Standard Specification for Chemical Admixtures for Concrete
C597-09
Standard Test Method for Pulse Velocity Through Concrete
C617/C617M-11
Standard Practice for Capping Cylindrical Concrete Specimens
C618-08
Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete
C641-09
Standard Test Method for Iron Staining Materials in Lightweight Concrete Aggregates
C666/C666M-03(2008)
Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing
C803/C803M-03
Standard Test Method for Penetration Resistance of Hardened Concrete
C805/C805M-08
Standard Test Method for Rebound Number of Hardened Concrete
C881/C881M-10
Standard Specification for Epoxy-Resin-Base Bonding Systems for Concrete
C900-06
Standard Test Method for Pullout Strength of Hardened Concrete
C979/C979M-10
Standard Specification for Pigments for Integrally Colored Concrete
C1017/C1017M-07
Standard Specification for Chemical Admixtures for Use in Producing Flowing Concrete
C1116/C1116M-10
Standard Specification for Fiber-Reinforced Concrete
C1193-11
Standard Guide for Use of Joint Sealants
C1240-11
Standard Specification for Silica Fume Used in Cementitious Mixtures
D75/D75M-09
Standard Practice for Sampling Aggregates
E488/E488M-10
Standard Test Methods for Strength of Anchors in Concrete and Masonry Elements

American Institute of Steel Construction
AISC 325-05
Steel Construction Manual, 13th edition

American Welding Society
AWS D1.1/D1.1M:2010
Structural Welding Code—Steel
AWS D1.4:2005
Structural Welding Code—Reinforcing Steel

Precast/Prestressed Concrete Institute
MNL-116-99
Manual for Quality Control for Plants and Production of Structural Precast Concrete Products, 4th edition
MNL-117-96
Manual for Quality Control for Plants and Production of Architectural Precast Concrete Products, 3rd edition

MNL-120-10
PCI Design Handbook: Precast and Prestressed Concrete, seventh edition
MNL-122-07
Architectural Precast Concrete, third edition
MNL-123-88
Design and Typical Details of Connections for Precast and Prestressed Concrete, second edition
MNL-135-00
Tolerance Manual for Precast and Prestressed Concrete Construction

Concrete Reinforcing Steel Institute, 2001, *Manual of Standard Practice*, 27th edition, CRSI, Schaumburg, IL 116 pp.

Concrete Reinforcing Steel Institute, 2005, *Placing Reinforcing Bars*, eighth edition, CRSI, Schaumburg, IL.

Gaylord, E., H., Jr.; Gaylord, C. N.; and Stallmeyer, J. E., 1996, *Structural Engineering Handbook*, fourth edition, McGraw-Hill Professional, 1248 pp.

Greening, N. R., and Landgren, R., 1966, "Surface Discoloration of Concrete Flatwork," *Journal of the PCA Research and Development Laboratories*, V. 8, No. 3, pp. 34-50.

Pfeifer, D. W., and Landgren, R., 1982, "Energy-Efficient Accelerated Curing of Concrete for Plant-Produced Prestressed Concrete," *PCI Journal*, V. 27, No. 2, 1982, pp. 94-107.

Portland Cement Association, 1988, "Removing Stains and Cleaning Concrete Surfaces," IS214T, PCA, Skokie, IL, 16 pp.

Precast/Prestressed Concrete Institute, 1988, "Recommendations on Responsibility for Design and Construction of Precast Concrete Structures," PCI Board Ad Hoc Committee for Responsibility for Design of Precast Concrete Structures," *PCI Journal*, V. 33, No. 4, 1988, pp. 44-52.

American Concrete Institute®
Advancing concrete knowledge

As ACI begins its second century of advancing concrete knowledge, its original chartered purpose remains "to provide a comradeship in finding the best ways to do concrete work of all kinds and in spreading knowledge." In keeping with this purpose, ACI supports the following activities:

· Technical committees that produce consensus reports, guides, specifications, and codes.

· Spring and fall conventions to facilitate the work of its committees.

· Educational seminars that disseminate reliable information on concrete.

· Certification programs for personnel employed within the concrete industry.

· Student programs such as scholarships, internships, and competitions.

· Sponsoring and co-sponsoring international conferences and symposia.

· Formal coordination with several international concrete related societies.

· Periodicals: the ACI Structural Journal and the ACI Materials Journal, and Concrete International.

Benefits of membership include a subscription to Concrete International and to an ACI Journal. ACI members receive discounts of up to 40% on all ACI products and services, including documents, seminars and convention registration fees.

As a member of ACI, you join thousands of practitioners and professionals worldwide who share a commitment to maintain the highest industry standards for concrete technology, construction, and practices. In addition, ACI chapters provide opportunities for interaction of professionals and practitioners at a local level.

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

www.concrete.org

Guide for Precast Concrete Wall Panels

The AMERICAN CONCRETE INSTITUTE

was founded in 1904 as a nonprofit membership organization dedicated to public service and representing the user interest in the field of concrete. ACI gathers and distributes information on the improvement of design, construction and maintenance of concrete products and structures. The work of ACI is conducted by individual ACI members and through volunteer committees composed of both members and non-members.

The committees, as well as ACI as a whole, operate under a consensus format, which assures all participants the right to have their views considered. Committee activities include the development of building codes and specifications; analysis of research and development results; presentation of construction and repair techniques; and education.

Individuals interested in the activities of ACI are encouraged to become a member. There are no educational or employment requirements. ACI's membership is composed of engineers, architects, scientists, contractors, educators, and representatives from a variety of companies and organizations.

Members are encouraged to participate in committee activities that relate to their specific areas of interest. For more information, contact ACI.

www.concrete.org

American Concrete Institute®
Advancing concrete knowledge