

ACI 303R-12

Guide to Cast-in-Place Architectural Concrete Practice

Reported by ACI Committee 303



American Concrete Institute®

Guide to Cast-in-Place Architectural Concrete Practice

Copyright by the American Concrete Institute, Farmington Hills, MI. All rights reserved. This material may not be reproduced or copied, in whole or part, in any printed, mechanical, electronic, film, or other distribution and storage media, without the written consent of ACI.

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

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

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

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

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

Participation by governmental representatives in the work of the American Concrete Institute and in the development of Institute standards does not constitute governmental endorsement of ACI or the standards that it develops.

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

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

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

www.concrete.org

ISBN 978-0-87031-771-2

Guide to Cast-in-Place Architectural Concrete Practice

Reported by ACI Committee 303

Chris A. Forster, Chair

Keith Ahal
George F. Baty
Eugene H. Boeke Jr.
Daniel P. Dorfmueller
Thomas J. Grisinger
Gardner P. Horst
James M. Shilstone Jr.

Michael S. Smith
David M. Suchorski
Claude B. Trusty Jr.
Gregory R. Wagner

The committee would like to thank the late Louis Tallarico for his contribution to this guide.

This guide presents recommendations for producing cast-in-place architectural concrete. The importance of specified materials, forming, concrete placement, curing, additional treatment, inspection, and their effect on the appearance of the finished product are discussed. Architectural concrete requires special construction techniques, materials, and requirements that are unique to each project. The specific recommendations and information presented in this guide should be used accordingly.

Keywords: admixture; aggregate; architectural concrete; beam; bush-hammer; cement; coating; column; consolidation; cracking; curing; deflection; exposed-aggregate finish; finish; form lining; formwork; joint; joint sealant; mixture proportion; pigment; placing; quality control; release agent; repair; retarder; sealant; texture; wall.

ACI Committee Reports, Guides, and Commentaries are intended for guidance in planning, designing, executing, and inspecting construction. This document is intended for the use of individuals who are competent to evaluate the significance and limitations of its content and recommendations and who will accept responsibility for the application of the material it contains. The American Concrete Institute disclaims any and all responsibility for the stated principles. The Institute shall not be liable for any loss or damage arising therefrom.

Reference to this document shall not be made in contract documents. If items found in this document are desired by the Architect/Engineer to be a part of the contract documents, they shall be restated in mandatory language for incorporation by the Architect/Engineer.

CONTENTS

Chapter 1—Introduction, p. 2

Chapter 2—Definitions, p. 2

Chapter 3—Architectural considerations, p. 3

- 3.1—Architectural features
- 3.2—Architectural design
- 3.3—Coatings and sealers
- 3.4—Joint sealants
- 3.5—Specifications

Chapter 4—Structural considerations, p. 7

- 4.1—Spalling
- 4.2—Deflections
- 4.3—Cracking
- 4.4—Joints
- 4.5—Beams and slabs
- 4.6—Columns
- 4.7—Walls

Chapter 5—Forms, p. 10

- 5.1—General
- 5.2—Materials

ACI 303R-12 supersedes ACI 303R-04 and became effective June 2012..

Copyright © 2012, American Concrete Institute

All rights reserved including rights of reproduction and use in any form or by any means, including the making of copies by any photo process, or by electronic or mechanical device, printed, written, or oral, or recording for sound or visual reproduction or for use in any knowledge or retrieval system or for information storage or in writing is obtained from the copyright proprietor.

- 5.3—Economics
- 5.4—Formwork accuracy
- 5.5—Form joints
- 5.6—Textures and patterns
- 5.7—Formwork accessories
- 5.8—Form coatings and sealers
- 5.9—Form release agents
- 5.10—Form removal

Chapter 6—Reinforcement, p. 18

- 6.1—General
- 6.2—Clear space
- 6.3—Reinforcement supports and spacers
- 6.4—Tie wire
- 6.5—Zinc-coated (galvanized) steel reinforcement
- 6.6—Epoxy-coated reinforcing bars

Chapter 7—Concrete materials and mixture proportioning, p. 20

- 7.1—General
- 7.2—Materials
- 7.3—Proportioning, mixing, and temperature control

Chapter 8—Placing and consolidation, p. 22

- 8.1—Conveying and placing
- 8.2—Consolidation

Chapter 9—Curing, p. 24

- 9.1—General
- 9.2—Curing in forms
- 9.3—Moist curing
- 9.4—Membrane curing
- 9.5—Hot weather curing

Chapter 10—Treated architectural surfaces, p. 24

- 10.1—Surface retarders
- 10.2—High-pressure water jet
- 10.3—Acid wash
- 10.4—Abrasive blasting
- 10.5—Tooling or other mechanical treatments

Chapter 11—Finishing and final cleanup, p. 26

- 11.1—General
- 11.2—Tie holes
- 11.3—Blemish repair
- 11.4—Stain removal
- 11.5—Sealers and coatings

Chapter 12—References, p. 27

Appendix A—Architectural concrete photos, p. 29

CHAPTER 1—INTRODUCTION

This guide presents recommendations for cast-in-place architectural concrete that is exposed to view. Architectural concrete requires special care in the selection of concrete materials, forming, placing, and finishing to achieve the desired architectural appearance. Refer to the photos in

Appendix A for examples of architectural cast-in-place concrete. Various procedures are recommended for determining requirements of the architect, contractor, concrete producer, and inspector. Critical areas are indicated for special attention, and means for prevention or correction of defects are discussed. Specific surface treatments and special forming techniques are presented. Applicable codes, specifications, and recommendations are given. A good resource for general information about architectural concrete can be found in several papers published in *Concrete International* (1984(a) to (i); 1988(a) to (h)), as well as the *Concrete Construction Engineering Handbook* (Kenny and Freedman 1997).

The information presented in this guide is broad and covers several special conditions for specific architectural concrete. Information that may be applicable for use in producing a specific result may not be applicable to another. The user should also be aware that recommendations in this guide are subjective to the means and methods used for accomplishing a specific task for a specific level of architectural effect, and should be tested before use to ensure it will produce the required result. Further research is needed to provide additional information on surface air voids and other construction problems. This guide does not address all the problems associated with architectural concrete.

CHAPTER 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.

blemish—any superficial defect that causes visible variation from a consistently smooth and uniformly colored surface of hardened concrete.

checking—development of shallow cracks at closely spaced but irregular intervals on the surface of plaster, cement paste, mortar, or concrete.

concrete, architectural—concrete that will be permanently exposed to view and therefore requires special care in the selection of the concrete materials, forming, placing, and finishing to obtain the desired architectural appearance.

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

concrete, exposed—concrete surfaces formed so as to yield an acceptable texture and finish for permanent exposure to view. (Refer to **concrete, architectural**.)

finish, exposed-aggregate—a decorative finish for concrete work achieved by removing, generally before the concrete has fully hardened, the outer skin of mortar and exposing the coarse aggregate.

finish, rubbed—a finish obtained by using an abrasive to remove surface irregularities from concrete. (Refer to **sack rub**.)

mottling—uneven color shading or blotchiness across a surface.

quality control—actions taken by an organization to provide control and documentation over what is being done and what is being provided so that the applicable requirements

good practice and the contract documents for the work are followed.

sack rub—a finish for formed concrete surfaces, designed to produce even texture and fill pits and air holes; after dampening the surface, mortar is rubbed over the surface; then, before the surface dries, a mixture of dry cement and sand is rubbed over it with either a wad of burlap or a sponge-rubber float to remove surplus mortar and fill voids.

sandblast—a system of cutting or abrading a surface such as concrete by a stream of sand ejected from a nozzle at high speed by compressed air; often used for cleanup of horizontal construction joints or for exposure of aggregate in architectural concrete.

snap tie—a proprietary concrete wall-form tie, the end of which can be twisted or snapped off after the forms have been removed.

texture—the pattern or configuration apparent in an exposed surface, as in concrete and mortar, including roughness, streaking, striation, or departure from flatness.

CHAPTER 3—ARCHITECTURAL CONSIDERATIONS

3.1—Architectural features

3.1.1 General acceptance criteria—Architecturally acceptable concrete surfaces should be aesthetically compatible with minimal color and texture variations and surface defects when viewed at a distance of approximately 20 ft (6 m) or more, as agreed upon by the architect, owner, and contractor, or as otherwise specified.

3.1.2 Measurement—It is beyond the scope of this guide to establish precise or definitive rules of measurement. Within any discrete building element or series of like elements, however, a high degree of visual uniformity is generally expected and required. The preconstruction mockup panel would normally be used to establish acceptance criteria (Section 3.5.4).

3.1.3 Variations in color and shading—Variations in color and shades within a color can be expected due to the many variables encountered with cast-in-place architectural concrete. These are minimized by:

- Quality control of ingredients, concrete mixtures, and consistency (Sections 7.2 and 7.3);
- Uniform concrete delivery schedules (Section 8.1.1);
- Uniformity of form surface, form release agent, application rate, and formwork reuse, erection, and stripping (Sections 5.10.2 to 5.10.4);
- Uniform rates of placement and consistent methods of placement and consolidation of concrete (Chapter 8);
- Placement schedules to minimize extreme variations of ambient conditions (Section 8.1.1);
- Consistent curing procedure and material (Chapter 9); and
- Properly timed or executed finishing operations (Chapter 11).

3.1.4 Finishes—Surface textures are grouped into two general classes:

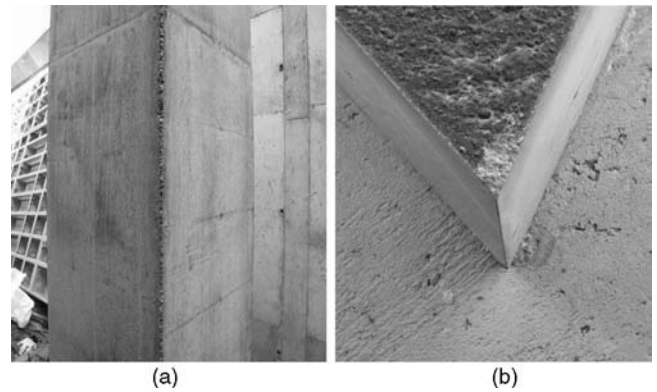


Fig. 3.2.2.1—(a) Difficult-to-achieve consolidation at acute corners; and (b) the use of SCC allows for proper consolidation at the acute corner.

- Untreated surfaces where the mortar is the principal visible constituent, and the texture is that which is imparted by the formwork sheathing or form liner; and
- Surfaces that are mechanically or chemically treated in place by removal of surface mortar to expose the underlying aggregate, thus wholly or partially obscuring the texture of the form sheathing or form liner.

High-build polymer coatings and cementitious or polymer-modified coatings that obscure both color and texture are not included in this guide.

3.2—Architectural design

3.2.1 General criteria—Architectural design criteria for readily obtainable and acceptable results should include:

- Isolation or division of concrete surfaces to allow reuse of formwork modules by the incorporation of rustication or joint patterns, or by the employment of a paneled effect;
- Systematic planning of construction joints that allows a reusable formwork module and conforms to structural requirements;
- Use of textured form sheathing (face sheets) or form liners, mechanically or chemically textured concrete finishes, or other relief features; and
- Limitations on the size of panels bounded by rustication or joint patterns; large, smooth, uninterrupted expanses of concrete surfaces should be avoided.

3.2.2 Details of architectural design

3.2.2.1 Unchamfered corners—Although acute- and right-angle corners can be obtained, they are difficult to construct and maintain, especially during construction. Proper consolidation of the concrete is essential, and self-consolidating concrete (SCC) may be required to achieve a crisp edge (Fig. 3.2.2.1). Forms should be designed and sealed to resist concrete placing pressures, and fabricated such that they can be stripped without damaging the concrete. Extended stripping time will probably be necessary to prevent damage to sharp corners that, depending on the size of the project, may require additional forms. Extended stripping time could also affect color because variation in form stripping times will increase the color differential.

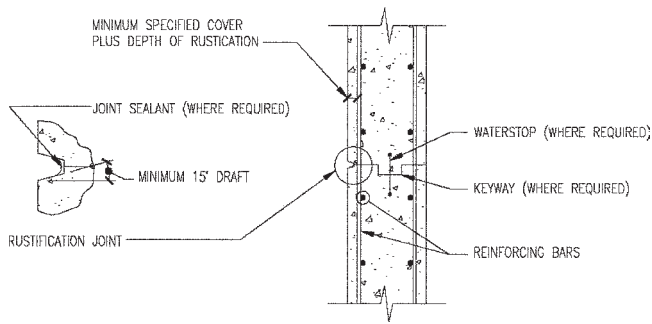


Fig. 3.2.2.3—Typical contraction joint detail.

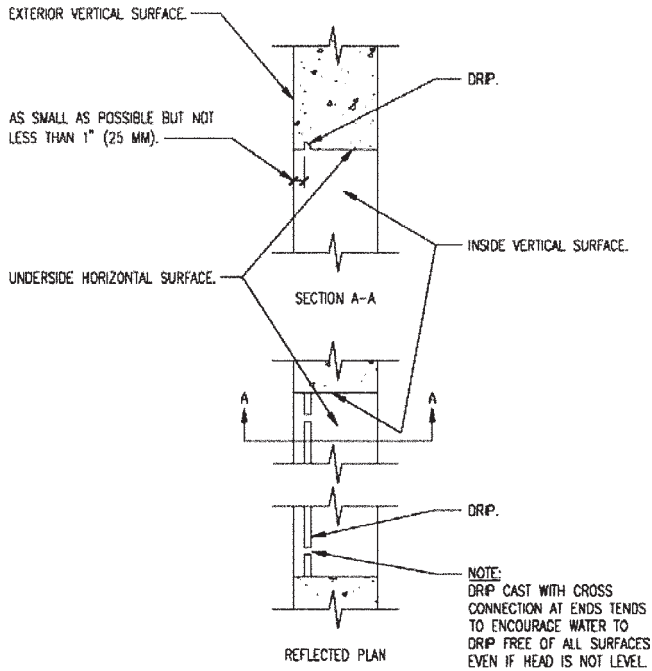


Fig. 3.2.2.4—Drip detail.

3.2.2.2 Chamfered corners—Where chamfers are part of the architectural feature, the chamfer form strip should be continuously tight to all form surfaces they contact. Plastic or metal chamfer strips are available that have integral means of sealing to the form contact surfaces. Wood chamfer strips are difficult to maintain continuously tight, unless a sealant is used when attaching to formwork.

3.2.2.3 Joints—Panel area joints may be recessed into the concrete surface by applying rustication strips on the formed surfaces. These can also be used for construction joints as needed by the contractor. Waterstops, keyways, and joint sealants may be included where required. Refer to Section 4.4 for recommended joint depths.

Formwork rustication strips should have a draft of at least 15 degrees to facilitate removal. Draft is defined as a small angle or taper in the formwork for reentrant formed surface that facilitates release when the form is stripped (Fig. 3.2.2.3). Also, wooden strips should be deeply sawcut or kerfed on the backside to prevent binding due to expansion from absorbed water.

All rustication strips or other inserts should be installed continuously tight to the form contact surface. Back-screwing the strip so it can be released before stripping may help obtain a tight seal. Nailing the strips to the form face for some architectural treatments may be acceptable but will not attain a tight seal. Insufficient nailing of the form strip will usually result in leakage and leave the reveal void ragged and discolored.

Rustication strips should be uniform in dimensions, nonabsorbent, and of sufficient stiffness to maintain alignment during concrete placement operations. In areas of possible deflection of the sheathing, a method of treatment to prevent mortar leakage should be used.

Metal chamfer or rustication strips and other materials of similar stiffness should have a minimum width of 3/4 in. (20 mm). Widths of wooden rustication strips should be at least equal to their depths. Joints smaller than recommended above can be attained with special form detailing using steel insert strips installed between the forms.

Intersections of chamfer or rustication strips should be mitered or coped to fit snugly. Chamfer, rustication, or isolation strips may be placed so as to cover form joints.

3.2.2.4 Soffits—A drip should be installed in soffits near vertical surfaces where there is a potential for downward movement of rainwater on the vertical concrete face (Fig. 3.2.2.4). The drip molds should be placed as near to the external vertical face as practicable, but not closer than 1 in. (25 mm) from the finished concrete surface. Note that the drip in Fig. 3.2.2.4 is interrupted at either end of the underside horizontal surface to help facilitate downward movement of water before it reaches the inside vertical face.

3.2.2.5 Sloped surfaces—Accumulation of airborne solids on horizontal surfaces can be minimized by sloping such surfaces. Sills should have a slight downward slope, and the upper surfaces of recesses should have an upward slope from the horizontal, relative to the inside face of the recess. Slopes may vary from 1:12 for smooth surfaces to 1:1 for textured surfaces (Fig. 3.2.2.5(a) and (b)).

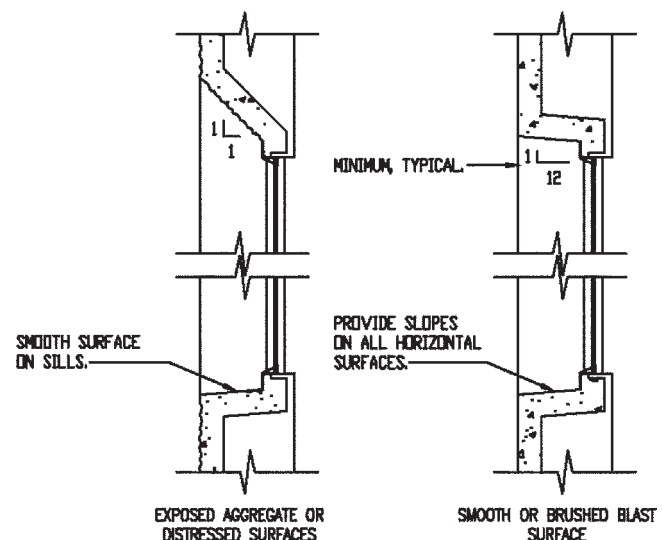


Fig. 3.2.2.5(a)—Suggestions for detail that will promote self-cleaning by facilitating the downward flow of water.

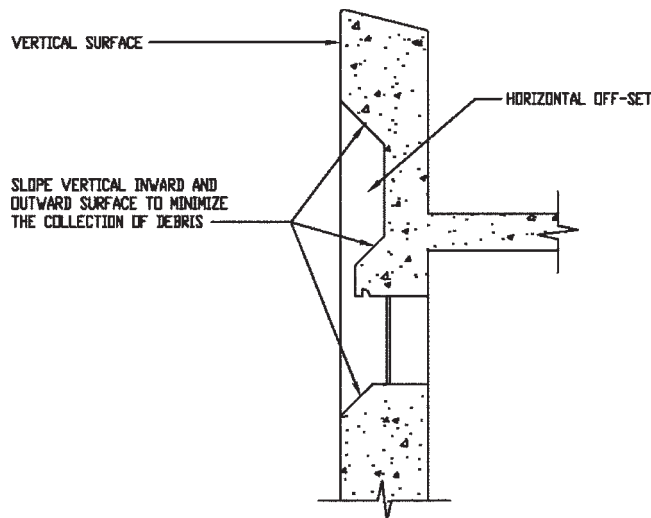


Fig. 3.2.2.5(b)—Deleterious airborne solids should not be afforded any horizontal surfaces on which to collect. A sloped surface should be provided.

On parapets, the slope should be away from the face. Unsloped horizontal offsets in vertical recesses and the use of textures on horizontal surfaces should be avoided. If a horizontal recess is formed without a drip near the exterior face, a slight upward slope, relative to the exterior face, should be provided (Fig. 3.2.2.5(c)).

Sloped and horizontal surfaces cast against a form will trap air bubbles as the concrete is consolidated. Special techniques and materials may be required to reduce trapped air, such as an absorbent form face. Refer to ACI 309R-05 for more information.

3.2.3 Combination with precast concrete—Cast-in-place architectural concrete and precast elements may be successfully combined using one of two site options:

1. On-site—Color and texture may be reasonably matched by on-site precasting at the same time cast-in-place work is done, using the same concrete mixture, materials, formwork techniques, and curing for both types of concrete; or
2. Off-site—Contrasting colors and textures in the design between off-site precast concrete and cast-in-place architectural elements are provided. In some cases, color and texture can be closely matched using dissimilar materials. A mockup panel can be used to demonstrate the match for approval by the architect.

Trying to achieve an exact match of cast-in-place concrete with precast units cast off-site is extremely difficult and may not be achievable. Nevertheless, both on-site and off-site combinations with precast concrete require detailed effort on the parts of the owner, architect, contractor, and inspector (Fig. 3.2.3).

3.3—Coatings and sealers

3.3.1 Purpose—Retention of original color and texture may be prolonged by surface application of clear, penetrating (vapor-transmitting) sealers that reduce surface moisture absorption and consequent weather staining.

Stains may be applied where it is desired to alter the natural color of the concrete and to retain its texture. Pigmented

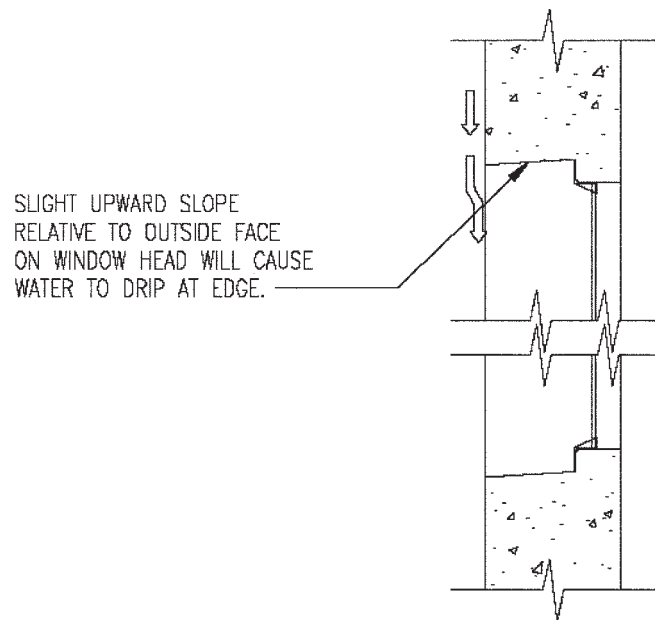


Fig. 3.2.2.5(c)—A slight upward slope will encourage rain-water to drip free if no drip is used.



Fig. 3.2.3—Architectural cast-in-place wall with precast window spandrels to match.

coatings drastically reduce vapor transmission, are not penetrating, and often alter both color and texture. They should be warranted by the manufacturer against changing color after exposure.



Fig. 3.5.4—Preconstruction mockup for the Getty Villas, Malibu, CA.

3.4—Joint sealants

Passage of moisture through construction and contraction joints should be prevented by filling the joints with sealants as recommended in ACI 224.3R-95. For architectural reasons, the sealant should be approved by the architect, match well in color and shape with the adjacent concrete surface, be nonstaining, and be chemically compatible with clear penetrating sealers.

3.5—Specifications

3.5.1 General—Specifications are customarily prepared as either performance, prescriptive, or a combination of both (Bell 1996):

- Performance specification—The quality of the end product is specified and, in this case, full responsibility is placed on the contractor. Recommended methods may be suggested.
- Prescriptive specification—Detailed methods, materials, and procedures are specified and, in this case, responsibility is shared by the designer and contractor with the purpose of the mockup being to confirm the specified materials and methods and to demonstrate the contractor's ability to produce the desired architectural finish.

Most exposed aggregate projects use a combination of performance and prescriptive specifications, where aggregate proportions, cement source, and minimum vibration frequency are specified to ensure success without specifying actual methods of construction.

3.5.2 Design reference sample—Surface quality and appearance requirements should be referenced for bidding purposes to an actual sample or samples exhibiting the desired surfaces, color, and texture.

The sample should be prepared under the architect's direction and labeled as the design reference sample (DRS). A minimum size of 18 x 18 x 2 in. (460 x 460 x 50 mm) provides sufficient area for display and thickness for surface tooling and allows for easy handling. The sample should



Fig. 3.5.4.a—Full-scale preconstruction mockup used for the Contemporary Arts Center, Cincinnati, OH.

be cast vertically or horizontally similar to the position in which the final concrete will be cast.

Design reference samples of walls or other representative building elements should be available for inspection and examination by prospective bidders. Mixture proportions, placement method, and sources of materials should also be provided. The samples should be confirmed in writing by both the owner and architect/engineer so as to have equal legal status with the contract documents.

In special cases, such as building additions or additional structures within a pre-existing group or complex, it may be acceptable to use an existing building for reference that contains elements of the desired quality and appearance.

3.5.3 Mandatory prebid conference—A mandatory prebid conference should be held between the architect/engineer and the prospective bidding contractors, where expectations and requirements are explained and clarified. An acceptable architectural finish should be presented as established by the contract documents. At this time, the contractors will have an opportunity to discuss aspects of the specifications that make it difficult or impossible to achieve the desired effect. Minutes of the prebid conference should be issued as part of the bid documents.

3.5.4 Preconstruction mockup—The preconstruction mockup (Fig. 3.5.4) is a full-scale sample of architectural concrete constructed on site by the contractor with proposed equipment, materials, and construction procedures. The contractor should obtain written approval of the finished product from the specifying agency and the owner after viewing at the agreed-upon distance before constructing the main structure.

The preconstruction mockup is normally constructed on the job site by the successful contractor before commencing the architectural portion of the work. On certain projects, an extra mockup may be constructed under a special contract to determine the feasibility of various materials, treatments, and procedures that are to be included in the architectural specifications for the project (Fig. 3.5.4.a).

The overall height and width of the full-scale mockup should allow the demonstration of floor, column, and wall construction. The mockup should incorporate both horizontal and vertical form or form liner joints, placing method and equipment, and all of the specified reinforcement, accessories, and curing materials and equipment. All construction materials for the mockup should be the same as those used during the actual construction of the project. Ideally, the main vibrator operator for the concrete in the final structure should also operate the vibrator during construction of the mockup.

The mockup should also include a repaired area to determine ahead of time an acceptable color and texture match for use if remedial work is needed. In evaluating this experimentally repaired area, the repair should be aged at least 1 month to allow enough time for a true indication of its color. To expedite construction of the project, a minimum of five variations of mixture color should be made for selection of the best match. Perfecting a repair procedure can save both time and money in the final outcome of the project.

Where feasible, architectural concrete placement, treatment, and procedures can be evaluated on portions of the structure eventually hidden from view, such as basement walls.

3.5.5 Shop drawings—Shop-drawing submittals are effective tools for reviewing the contractor's plans for construction. The shop drawings should include:

- Details of the formwork aspects of the project, including form butt joints, rustications or reveals, and construction joints. They should convey to the architect the means and methods the contractor will be using to fabricate and erect the formwork and show how the forms will be maintained to ensure tightness against leakage and alignment during concrete placement;
- Cover of reinforcing steel; and
- Description of the placing operation, including the method of conveying concrete to the forms, wall placement lengths and lift heights, soffit deposit sequences, and vibration techniques.

3.5.6 Inspection and quality control

3.5.6.1 General—The architect, contractor, project inspector, suppliers, and other parties involved with the production of the architectural concrete may interpret the results of the finished product differently. These interpretations may vary during progress of the work, especially in circumstances where expectations of the outcome appear impossible to achieve if maintaining the existing practice of construction and materials. To avoid ambiguities midway through the project, the inspector should review the specifications early on, meeting with the architect/engineer and contractor after the mockup has been constructed, and confirming established criteria for evaluating the final product (ACI SP-2 1999). Section 3.5.6 addresses additional concerns not covered in ACI SP-2 (1999).

3.5.6.2 Qualification of the inspector—The inspector should have experience in the inspection of architectural concrete of equivalent complexity and scope. The extent of the inspector's responsibility is determined by the architect/engineer. Confirmation of this responsibility is developed at

the prebid and postbid conferences with the contractors. The architect and inspector should hold periodic conferences to discuss the progress and quality of the work. On major projects where different operations are proceeding concurrently, more than one inspector may be required to inspect the work.

3.5.6.3 Duties of the inspector—The duties and responsibilities of the inspector should include:

- Reviewing project documents in advance of the prebid conference and advising the architect/engineer of changes that may be required to produce the desired results;
- Inspecting and personally observing the manufacture of the prebid samples. This will provide the inspector with invaluable knowledge and experience regarding the mixture, slump, color, and placing characteristics of the concrete. During the contract period that follows, any variation would immediately become apparent;
- Attending the prebid conference to assist the architect/engineer in clarifying the intent of the specifications;
- Being present during construction of the preconstruction mockup to observe and evaluate the materials and techniques used to produce and repair the panel. The inspector, after completion of these efforts, will be ready to assist the architect/engineer in evaluating the quality of the completed architectural concrete work;
- Providing inspection of materials used for concrete mixture, forming or texturing, form release agents and their application, form alignment, tightness of the form joints, rustication fastening, placement of reinforcing steel relative to the exposed face, curing before and subsequent to the form stripping, required repairs, and final clean-down. Each of these contributes to the appearance of the finished surface of the architectural concrete; and
- Observing and recording the condition of the architectural forms after each reuse and consulting with the contractor and architect when the forms need to be replaced or refurbished to achieve uniformity of the architectural surface.

3.5.6.4 Final acceptance—If the procedures determined by the approved on-site mockup are continued throughout the project, final acceptance at the agreed-upon distance should not be a problem. Due to the inevitable nonuniformity of construction practices, some repairs will be required. Their final acceptability will depend on the contractor's blending technique and skill. Periodic review by the inspector and the architect/engineer to allow partial acceptance creates goodwill and confidence with all concerned. After final acceptance, the inspector's records should be completed and filed. If later additions are made or adjoining buildings constructed, these records will be helpful for construction.

CHAPTER 4—STRUCTURAL CONSIDERATIONS

Structural and architectural design should function together to produce a structure capable of withstanding service loads and stresses without excessive cracking, spalling, or deflection that may detract from the architectural appearance of the structure.

4.1—Spalling

In their design, the architect and engineer should pay special attention to applied loads at joints where movement can occur and cause spalling.

4.2—Deflections

The use of strength design requires strict investigation for undesirable deflections in beams or spandrels exposed as architectural concrete. The desired camber should be specified to compensate for the deflection of the completed structural member. Consideration should also be given to additional long-term deflection due to creep of concrete under permanent loads. Architectural requirements may dictate that the engineer design for deflections less than normally acceptable. They may also require additional camber to avoid the impression of sagging in long spans. Excessive camber can, in some cases, be as objectionable as sag.

4.3—Cracking

Cracking in architectural concrete can be unsightly. Practices to reduce and control cracking to minimize the effect on appearance and durability should be used.

Factors that influence concrete cracking are:

- Gravity or lateral loads that produce tension, shear, or torsion in members;
- Restraint of drying shrinkage;
- Creep;
- Abrupt change in geometry, such as concrete thickness;
- Axial or bending stresses due to thermal effects; and
- Foundation settlement.

Cracking may be reduced by:

- Adding reinforcement, closure strips, and other methods at bearings or slip joints as needed to correct axial shortening and rotation due to post-tensioning;
- Limiting the flexural tension stress in reinforcement;
- Distributing flexural reinforcement when appropriate (ACI 318-11);
- Using special materials, such as shrinkage-reducing admixtures, shrinkage-compensating cements, and aggregates with low shrinkage characteristics, or selected proportions of these (ACI 223R-10);
- Minimizing the total water content, along with the water-cementitious material ratio (w/cm) of the concrete mixture by optimizing the aggregate grading. Some water-reducing admixtures may increase shrinkage despite a reduction in water;
- Minimizing the change in member-to-member geometry or mass;
- Evaluating trial batches with various combinations of aggregates, cements, and admixtures, and checking for shrinkage using ASTM C157/C157M-08;
- Increasing the shrinkage and temperature reinforcement above the minimum requirements in ACI 318-11;
- Minimizing thermal stresses by controlling heat of hydration and cooling; and
- Providing joints or crack-inducing devices to relieve stress.

In addition to the aforementioned methods, cracking can often be minimized by attention to joint placement, which



Fig. 4.4—Rustication strips used to break up a large expanse of concrete.

relieves the shrinkage stresses and directs the cracking to joints that are integral with the designed surface presentation. This is often achieved through rustication or reveals on the concrete surface with internal devices, which weaken the concrete at predetermined lines to induce the concrete to crack at that location. An induced crack should be sealed when exposed to weather to prevent water penetration. This is done by applying sealant in the surface rustication or reveal void or by placing a waterstop-type internal crack-inducing device in the concrete.

4.4—Joints

Construction joints divide the structure into segments that can be constructed in a logical and efficient manner; contraction joints are used in walls and slabs-on-ground to control cracking; and isolation joints are used in slabs-on-ground to separate them from walls, columns, or other structural elements. Details should be shown in the project drawings.

Rustication strips (Fig. 4.4) provide the simplest method of architecturally treating joints where surfaces in the same plane are joined. They reduce both the effective size of the members and the cover over the reinforcing steel. Additional compensating cover or a protective coating on the reinforcement should be provided (Fig. 3.2.2.3).

Recommended joint depths follow:

- Small rustication or pattern grooves: 3/4 in. (20 mm);
- Joint depths to initiate cracking: Approximately 20 percent of the member thickness, that is, 1-1/2 in. (38 mm) deep for an 8 in. (200 mm) thick wall or slab; and
- Joints between panel divisions should be at least 1-1/2 in. (38 mm) deep.

A large structure containing drastic changes in section size or exposure should be designed with either expansion or delayed pour joints to control cracking and allow for movement. All joints and rustications should be shown on the contract drawings. Refer to ACI 224.3R-95 for detailed information regarding joints in concrete construction.

4.5—Beams and slabs

The structural and architectural design of beams and slabs requires careful consideration because all the factors that

produce tension in concrete may be present in portions of the member.

Rustication depths should be kept to the minimum recommended size at the top and bottom of beams in regions of flexural tension. When the typical concrete cover on the steel is increased excessively by the depth of the rustication strip, any cracks that occur in the flexural tension zone will also be increased in width. Sandblasting accentuates the width of a crack due to rounding of its edge, especially at soffits of beams and slabs. Connections that are intended to allow substantial rotation or displacement should be designed and detailed to prevent spalling and leaking from weather exposure.

Openings in slabs induce cracks from the corners of the openings. Diagonal bars placed in the corners of the slab openings are effective in preventing or minimizing crack width at these locations. The slab should have sufficient thickness to accommodate these bars and the design reinforcement. The effect of openings on the structural capacity of slabs must be reviewed by the architect/engineer.

4.6—Columns

Typically, concrete columns do not have the high tensile stresses present in beams. The lateral dimensions are usually small and there is less tendency for vertical cracking. The small lateral dimensions also allow for rapid concrete placement compared to other elements. This tends to eliminate some of the problems associated with slow concrete placement such as cold joints and mortar splatter. Columns associated with long span beams may have a tendency to exhibit horizontal cracking as they become loaded because long span beams will generally induce greater bending moments in columns than comparable shorter span beams. Thermal movements and movement due to concrete shrinkage can also cause horizontal cracking in columns. The engineer should take these added effects into consideration when designing the column reinforcing.

4.7—Walls

The typical wall is relatively long, and may be tall, compared to its thickness. Normally in compression vertically, horizontal cracking is generally not a problem, but horizontal cracks may develop where a wall receives significant lateral loading or supports other elements that produce vertical bending moments. Horizontal cracking can occur when the concrete further consolidates subsequent to vibration of thick walls. These cracks can be prevented by ensuring that each lift is integrated with the previous lift by using a good vibrator spacing and insertion time. The most common cracking in walls is generally vertical or nearly vertical. The primary cause of vertical cracks in walls is axial tension caused by restrained drying shrinkage, temperature stresses, or both.

Construction joints are normally provided at the bottom and top of slabs at the intersection of the walls and slabs. Construction joints should also be provided at other locations necessary for construction and to control cracking. These joints should be concealed, rusticated, or empha-

sized. Joints required for construction should be coordinated between the contractor and the architect/engineer.

Vertical construction joints in long walls may be necessary at midspan or at some multiple of the bay length. An architectural approach is to provide for vertical rustications at a uniform spacing in all bays. This provides the contractor greater flexibility in planning the construction operation.

Vertical construction joints with rustication strips can be detailed as joints to accommodate volume-change movements and to reduce the horizontal extent of the casting operation, or can be detailed as crack-control joints. This permits the acceleration of the vertical rate of casting that, particularly in hot weather, will eliminate or make manageable the problems associated with surface air voids, form spatter, cold joints, and lift lines. Form spatter is mortar splashed on forms that is allowed to dry before covering with concrete. This creates a nonuniform surface that positively affects the architectural appearance. The architect/engineer should consider the formwork panel size in planning the joint locations; form-facing material joints may be visible on the concrete surface even though subsequent mechanical finishing is performed on the hardened concrete surfaces.

An effective method for controlling vertical cracking is providing contraction joints at a uniform spacing of not more than 20 ft (6 m) on center by placing deep (1.5 times the maximum aggregate size), narrow rustication strips on both wall faces to induce cracking. Any of the contraction joint locations can also be used for construction joints.

Consideration should be given to reducing the reinforcement crossing contraction and construction joints that are used for crack control. Suggested reinforcement crossing either type of joint should not exceed 1/2 of the horizontal reinforcement elsewhere in the wall. The minimum horizontal reinforcement required in walls by ACI 318-11 may be increased to minimize the widths of cracks that may occur between joints.

Consideration may also be given to the use of fiber reinforcement as a means of reducing the width of the visible crack. Fibers may be seen at the surface and should be approved in the mockup.

Openings in walls induce cracks from the corners of the openings. When horizontal steel is interrupted by openings, additional steel equivalent to that interrupted should be placed 1/2 above and below the opening, with a minimum steel extension 1.5 times the development length beyond the opening. Diagonal bars placed in the corners of the wall openings are also effective in preventing or minimizing crack width at these locations. The wall should have sufficient thickness to accommodate these bars and the normal horizontal and vertical reinforcement. Vertical or horizontal joints placed at the jambs or at the top and bottom of the opening, respectively, can also effectively be used to control cracks emanating from corners of openings (Fig. 4.7).

If nonstructural walls are used by the architect as part of the design, structural considerations should be reviewed and indicated in the contract documents.