Guide for Concrete Floor and Slab Construction

Reported by ACI Committee 302

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FOREWORD

The quality of a concrete floor or slab is highly dependent on achieving a hard and durable surface that is flat, relatively free of cracks, and at the proper grade and elevation. Properties of the surface are determined by the mixture proportions and the quality of the concreting and jointing operations. The timing of concreting operations—especially finishing and jointing—is critical. Failure to address this issue can contribute to undesirable characteristics in the wearing surface such as cracking, low resistance to wear, dusting, scaling, high or low spots, and poor drainage, as well as increasing the potential for curling.

Concrete floor slabs employing portland cement, regardless of slump, will start to experience a reduction in volume as soon as they are placed. This phenomenon will continue as long as any water or heat, or both, is being released to the surroundings. Moreover, since the drying and cooling rates at the top and bottom of the slab will never be the same, the shrinkage will vary throughout the depth, causing the as-cast shape to be distorted, as well as reduced in volume.

This guide contains recommendations for controlling random cracking and edge curling caused by the concrete's normal volume change. Application of present technology permits only a reduction in cracking and curling, not their elimination. Even with the best floor designs and proper construction, it is unrealistic to expect completely crack-free and curl-free results. Consequently, every owner should be advised by both the designer and contractor that it is completely normal to expect some amount of cracking and curling on every project, and that such occurrence does not necessarily reflect adversely on either the competence of the floor's design or the quality of its construction.[1,2] Refer to the latest edition of ACI 360 for a detailed discussion of shrinkage and curling in slabs on ground. Refer to the latest edition of ACI 224 for a detailed discussion of cracking in reinforced and nonreinforced concrete slabs.

This guide describes how to produce high quality concrete slabs on ground and suspended floors for various classes of service. It emphasizes such aspects of construction as site preparation, concreting materials, concrete mixture proportions, concreting workmanship, joint construction, load transfer across joints, form stripping procedures, and curing. Finishing methods, flatness/levelness requirements, and measurements are outlined. A thorough preconstruction meeting is critical to facilitate communication among key participants and to clearly establish expectations and procedures that will be employed during construction. Adequate supervision and inspection are required for job operations, particularly those of finishing.

Keywords: admixtures; aggregates; concrete construction; concrete durability; concrete finishing (fresh concrete); concrete slabs; consolidation; contract documents; cracking (fracturing); curing; curling; deflection; floor toppings; floors; forms; form stripping; heavy-duty floors; inspection; joints (junctions); mixture proportioning; placing; quality control; site preparation; slab-on-ground construction; slump tests; specifications; standards; suspended slabs.

CONTENTS

CHAPTER 1—INTRODUCTION

1.1—Purpose and scope

This guide presents state-of-the-art information relative to the construction of slab-on-ground and suspended-slab floors for industrial, commercial, and institutional buildings. It is applicable to the construction of normal weight and structural

lightweight concrete floors and slabs made with conventional portland and blended cements.

The design of slabs on ground should conform to the recommendations of ACI 360R. Refer to ACI 223 for special procedures recommended for the design and construction of shrinkage-compensating concrete slabs on ground. The design of suspended floors should conform to requirements of ACI 318 and ACI 421.1R. See Section 1.2 for relevant work by these and other committees.

This guide identifies the various classes of floors as to
•use,
•design details as they apply to construction,
•necessary site preparation, and
•type of concrete and related materials.

In general, the characteristics of the concrete slab surface and the performance of joints have a powerful impact on the serviceability of floors and other slabs. Since the eventual success of a concrete floor installation is greatly dependent upon the mixture proportions and floor finishing techniques used, considerable attention is given to critical aspects of achieving the desired finishes and the required floor surface tolerances. This guide emphasizes choosing and proportioning of materials, design details, proper construction methods, and workmanship.

1.1.1 *Prebid and preconstruction meetings*—While this guide does provide a reasonable overview of concrete floor construction, it should be emphasized that every project is unique; circumstances can dictate departures from the recommendations contained here. Accordingly, contractors and suppliers are urged to make a thorough formal review of contract documents *prior to bid preparation*.

The best forum for such a review is the *prebid meeting*. This meeting offers bidders an opportunity to ask questions and to clarify their understanding of contract documents prior to submitting their bids. A prebid meeting also provides the owner and the owner's designer an opportunity to clarify intent where documents are unclear, and to respond to last-minute questions in a manner that provides bidders an opportunity to be equally responsive to the contract documents.

1.1.2 *Preconstruction meeting*—Construction of any slab-on-ground or suspended floor or slab involves the coordinated efforts of many subcontractors and material suppliers. It is strongly recommended that a *preconstruction meeting* be held to establish and coordinate procedures that will enable key participants to produce the best possible product under the anticipated field conditions. This meeting should be attended by responsible representatives of organizations and material suppliers directly involved with either the design or construction of floors.

The preconstruction meeting should confirm and document the responsibilities and anticipated interaction of key participants involved in floor slab construction. Following is a list of agenda items appropriate for such a meeting; many of the items are those for which responsibility should be clearly established in the contract documents. The list is not necessarily all-inclusive.

1. Site preparation
2. Grades for drainage, if any

3. Work associated with installation of auxiliary materials, such as vapor barriers, vapor retarders, edge insulation, electrical conduit, mechanical sleeves, drains, and embedded plates
4. Class of floor
5. Floor thickness
6. Reinforcement, when required
7. Construction tolerances: base (rough and fine grading), forms, slab thickness, surface configuration, and floor flatness and levelness requirements (including how and when measured)
8. Joints and load transfer mechanism
9. Materials: cements, fine aggregate, coarse aggregate, water, and admixtures (usually by reference to applicable ASTM standards)
10. Special aggregates, admixtures, or monolithic surface treatments, where applicable
11. Concrete specifications, to include the following:
   a. Compressive and/or flexural strength and finishability (Section 6.2)
   b. Minimum cementitious material content, if applicable (Table 6.2.4)
   c. Maximum size, grading, and type of coarse aggregate
   d. Grading and type of fine aggregate
   e. Air content of concrete, if applicable (Section 6.2.7)
   f. Slump of concrete (Section 6.2.5)
   g. Water-cement ratio or water-cementitious material ratio
   h. Preplacement soaking requirement for lightweight aggregates
12. Measuring, mixing, and placing procedures (usually by reference to specifications or recommended practices)
13. Strikeoff method
14. Recommended finishing methods and tools, where required
15. Coordination of floor finish requirements with those required for floor coverings such as vinyl, ceramic tile, or wood that are to be applied directly to the floor
16. Curing procedures, including length of curing and time prior to opening the slab to traffic (ACI 308)
17. Testing and inspection requirements
18. Acceptance criteria and remedial measures to be used, if required

1.1.2.1 Additional issues specific to *suspended slab construction* are as follows:
1. Form tolerances and preplacement quality assurance survey procedures for cast-in-place construction
2. Erection tolerances and preplacement quality assurance survey procedures for composite slab construction; see ANSI/ASCE 3-91 and ANSI/ASCE 9-91 (Section 12.1).
3. Form stripping procedures, if applicable
4. Items listed in Section 3.3

1.1.3 *Quality control*—Adequate provision should be made to ensure that the constructed product meets or exceeds the requirements of the project documents. Toward this end, *quality control* procedures should be established and maintained throughout the entire construction process.

The quality of a completed concrete slab depends on the skill of individuals who place, finish, and test the material. As an aid to assuring a high-quality finished product, the specifier or owner should consider requiring the use of prequalified concrete contractors, testing laboratories, and concrete finishers who have had their proficiency and experience evaluated through an independent third-party certification program. ACI has developed programs to train and to certify concrete flatwork finishers and concrete testing technicians throughout the United States and Canada.

1.2—Work of other relevant committees

1.2.1 *ACI committees*

117—Prepares and updates tolerance requirements for concrete construction.

201—Reviews research and recommendations on durability of concrete and reports recommendations for appropriate materials and methods.

211—Develops recommendations for proportioning concrete mixtures.

223—Develops and reports on the use of shrinkage-compensating concrete.

224—Studies and formulates recommendations for the prevention or control of cracking in concrete construction.

301—Develops and maintains standard specifications for structural concrete for buildings.

308—Prepares guidelines for type and amount of curing required to develop the desired properties in concrete.

309—Studies and reports on research and development in consolidation of concrete.

318—Develops and updates building code requirements for reinforced concrete and structural plain concrete, including suspended slabs.

325—Reports on the structural design, construction, maintenance, and rehabilitation of concrete pavements.

330—Reports on the design, construction, and maintenance of concrete parking lots.

332—Gathers and reports on the use of concrete in residential construction.

347—Gathers, correlates, and reports information and prepares recommendations for formwork for concrete.

360—Develops and reports on criteria for design of slabs on ground, except highway and airport pavements.

421—Develops and reports on criteria for suspended slab design.

423—Develops and reports on technical status, research, innovations, and recommendations for prestressed concrete.

503—Studies and reports information and recommendations on the use of adhesives for structurally joining concrete, providing a wearing surface, and other uses.

504—Studies and reports on materials, methods, and systems used for sealing joints and cracks in concrete structures.

515—Prepares recommendations for selection and application of protective systems for concrete surfaces.

544—Studies and reports information and recommendations on the use of fiber reinforced concrete.

640—Develops, maintains, and updates programs for use in certification of concrete construction craftspeople.

1.2.2 *The American Society of Civil Engineers*—Publishes documents that can be helpful for floor and slab construction. Two publications that deal with suspended slab construction are the "ASCE Standard for the Structural Design of Composite Slabs" (ANSI/ASCE 3-91) and "ASCE Standard Practice for Construction and Inspection of Composite Slabs" (ANSI/ASCE 9-91).

CHAPTER 2—CLASSES OF FLOORS

2.1—Classification of floors

Table 2.1 classifies floors on the basis of intended use, discusses special considerations, and suggests finishing techniques for each class of floor. Use requirements should be considered when selecting concrete properties (Section 6.1), and the step-by-step placing, consolidating, and finishing procedures in Chapter 8 should be closely followed for different classes and types of floors.

Wear resistance should also be considered. Currently, there are no standard criteria for evaluating the wear resistance of a floor, and it is not possible to specify concrete quality in terms of ability to resist wear. Wear resistance is directly related to the concrete-mixture proportions, types of aggregates, and construction techniques used.

2.2—Single-course monolithic floors: Classes 1, 2, 4, 5, and 6

Five classes of floors are constructed with monolithic concrete; each involves some variation in strength and finishing techniques. If abrasion from grit or other materials will be unusually severe, a higher-quality floor surface may be required for satisfactory service.[3] Under these conditions, a higher-class floor, a special metallic or mineral aggregate monolithic surface treatment, or a higher-strength concrete is recommended.

2.3—Two-course floors: Classes 3, 7 and 8

2.3.1 *Unbonded topping over base slab*—The base courses of Class 3 (unbonded, two course) floors and Class 8 floors can be either slabs-on-ground or suspended slabs, with the finish to be coordinated with the type of topping. For Class 3 floors, the concrete topping material is similar to the base slab concrete. The top courses for Class 8 floors require a hard-steel troweling, and usually have a higher strength than the base course. Class 8 floors can also make use of an embedded hard aggregate, or a premixed (dry-shake) mineral aggregate or metallic hardener for addition to the surface (Section 5.4.6).

Class 3 (with unbonded topping) and Class 8 floors are used when it is preferable not to bond the topping to the base course, so that the two courses can move independently (for example, with precast members as a base), or so that the top courses can be more easily replaced at a later period. Two-course floors can be used when mechanical and electrical equipment require special bases, and when their use permits more expeditious construction procedures. Two-course unbonded floors can also be used to resurface worn or damaged floors when contamination

Table 2.1—Floor classifications

Class	Anticipated type of traffic	Use	Special considerations	Final finish
1 Single course	Exposed surface—foot traffic	Offices, churches, commercial, institutional, multiunit residential Decorative	Uniform finish, nonslip aggregate in specific areas, curing Colored mineral aggregate, color pigment or exposed aggregate, stamped or inlaid patterns, artistic joint layout, curing	Normal steel-troweled finish, nonslip finish where required As required
2 Single course	Covered surface—foot traffic	Offices, churches, commercial, gymnasiums, multiunit residential, institutional with floor coverings	Flat and level slabs suitable for applied coverings, curing. Coordinate joints with applied coverings	Light steel-troweled finish
3 Two course	Exposed or covered surface—foot traffic	Unbonded or bonded topping over base slab for commercial or non-industrial buildings where construction type or schedule dictates	*Base slab*—good, uniform, level surface, curing *Unbonded topping*—bond-breaker on base slab, minimum thickness 3 in. (75 mm) reinforced, curing *Bonded topping*—properly sized aggregate, $3/4$ in. (19 mm) minimum thickness curing	*Base slab*—troweled finish under unbonded topping; clean, textured surface under bonded topping *Topping*—for exposed surface, normal steel-troweled finish. For covered surface, light steel-troweled finish
4 Single course	Exposed or covered surface—foot and light vehicular traffic	Institutional and commercial	Level and flat slab suitable for applied coverings, nonslip aggregate for specific areas, curing. Coordinate joints with applied coverings	Normal steel-troweled finish
5 Single course	Exposed surface—industrial vehicular traffic, that is, pneumatic wheels, and moderately soft solid wheels	Industrial floors for manufacturing, processing, and warehousing	Good uniform subgrade, joint layout, abrasion resistance, curing	Hard steel-troweled finish
6 Single course	Exposed surface—heavy duty industrial vehicular traffic, that is, hard wheels, and heavy wheel loads	Industrial floors subject to heavy traffic; may be subject to impact loads	Good uniform subgrade, joint layout, load transfer, abrasion resistance, curing	Special metallic or mineral aggregate surface hardener; repeated hard steel-trowelling
7 Two course	Exposed surface—heavy duty industrial vehicular traffic, that is, hard wheels, and heavy wheel loads	Bonded two-course floors subject to heavy traffic and impact	*Base slab*—good, uniform subgrade, reinforcement, joint layout, level surface, curing *Topping*—composed of well-graded all-mineral or all-metallic aggregate. Minimum thickness $3/4$ in. (19 mm). Metallic or mineral aggregate surface hardener applied to high-strength plain topping to toughen, curing	Clean, textured base slab surface suitable for subsequent bonded topping. Special power floats for topping are optional, hard steel-troweled finish
8 Two course	As in Class 4, 5, or 6	Unbonded toppings—on new or old floors or where construction sequence or schedule dictates	Bondbreaker on base slab, minimum thickness 4 in. (100 mm), abrasion resistance, curing	As in Class 4, 5, or 6
9 Single course or topping	Exposed surface—super-flat or critical surface tolerance required. Special materials-handling vehicles or robotics requiring specific tolerances	Narrow-aisle, high-bay warehouses; television studios, ice rinks	Varying concrete quality requirements. Shake-on hardeners cannot be used unless special application and great care are employed. Ff50 to Ff125 ("superflat" floor). Curing	Strictly follow finishing techniques as indicated in Section 8.9

prevents complete bond, or when it is desirable to avoid scarifying and chipping the base course and the resultant higher floor elevation is compatible with adjoining floors. Class 3 floors are used primarily for commercial or non-industrial applications, whereas Class 8 floors are primarily for industrial-type applications.

Plastic sheeting, roofing felt, or a bond-breaking compound are used to prevent bond to the base slab. Reinforcement such as deformed bars, welded wire fabric, bar mats or fibers may be placed in the topping to reduce the width of shrinkage cracks. Unbonded toppings should have a minimum thickness of 3 in. (75 mm). The concrete should be proportioned to meet the requirements of Chapter 6. Joint spacing in the topping must be coordinated with joint spacing in the base slab.

2.3.2 *Bonded topping over base slab*—Class 3 (bonded topping) and Class 7 floors employ a topping bonded to the base slab. Class 3 (bonded topping) floors are used primarily for commercial or nonindustrial applications; Class 7 floors are used for heavy-duty, industrial-type applications subject to heavy traffic and impact. The base slabs can be either a conventional portland cement concrete mixture or shrinkage-compensating concrete. The surface of the base slab should have a rough, open pore finish and be free of any substances that would interfere with the bond of the topping to the base slab.

The topping can be either a same-day installation (prior to hardening of the base slab) or a deferred installation (after the base slab has hardened). The topping for a Class 3 floor is a concrete mixture similar to that used in Class 1 or 2 floors. The topping for a Class 7 floor requires a multiple-pass, hard-steel-trowel finish, and it usually has a higher strength than the base course. A bonded topping can also make use of an embedded hard aggregate or a premixed (dry-shake) mineral aggregate or metallic hardener for addition to the surface (Section 5.4.6). Bonded toppings should have a minimum thickness of $^3/_4$ in. (19 mm). Joint spacing in the topping must be coordinated with joint spacing in the base slab.

2.4—Class 9 floors

Certain materials-handling facilities (for example, high-bay, narrow-aisle warehouses) require extraordinarily level and flat floors. The construction of such "superflat" floors (Class 9) is discussed in Chapter 8. A superflat floor could be constructed as a single-course floor, or it could be constructed as a two-course floor with a topping, either bonded (similar to a Class 7 topping) or unbonded (similar to a Class 8 topping).

2.5—Special finish floors

Floors with decorative finishes and those requiring skid resistance or electrical conductivity are covered in appropriate sections of Chapter 8

Floors exposed to mild acids, sulfates, or other chemicals should receive special preparation or protection. ACI 201.2R reports on means of increasing the resistance of concrete to chemical attack. Where attack will be severe, wear-resistant protection suitable for the exposure should be used. Such environments, and the methods of protecting floors against them, are discussed in ACI 515.1R.

In certain chemical and food processing plants, such as slaughterhouses, exposed concrete floors are subject to slow disintegration due to organic acids. In many instances it is preferable to protect the floor with other materials such as acid-resistant brick, tile, or resinous mortars (ACI 515.1R).

CHAPTER 3—DESIGN CONSIDERATIONS

3.1—Scope

This chapter addresses design of concrete floors as it relates to their constructability. Components of a typical slab on ground[4] are shown in Fig. 3.1. Specific design requirements for concrete floor construction are found in other documents: ACI 360R for slabs on ground, ACI 223 for shrinkage-compensating concrete floors, ACI 421.1R for suspended floors, ANSI/ASCE 3-91 for structural design of composite slabs, and ANSI/ASCE 9-91 for construction and inspection of composite slabs. Refer to ACI 318 for requirements relating to the building code.

3.2—Slabs on ground

3.2.1 *Suggested design elements*—The following items should be specified in the contract documents prepared by the engineer of record.

- Base and subbase materials, preparation requirements, and vapor retarder, if required
- Concrete thickness[5]
- Concrete compressive, or flexural strength, or both
- Concrete mixture design requirements (ASTM C 94)
- Joint locations and details
- Reinforcement (type, size, and location), if required
- Surface treatment, if required
- Surface finish
- Tolerances (base, subbase, slab thickness, and surface)
- Curing
- Joint filling material and installation
- Special embedments
- Preconstruction meeting, quality assurance, and quality control

3.2.2 *Soil support system*—The performance of a slab on ground depends on the integrity of both the soil support system and the slab, so specific attention should be given to the site preparation requirements, including proof-rolling, discussed in Section 4.1.1. In most cases, proof-rolling results are far more indicative of the ability of the soil support system to withstand loading than are the results from in-place tests of moisture content or density. A thin layer of graded, granular, compactible material is normally used as fine grading material to better control the thickness of the concrete and to minimize friction between the base material and the slab.

3.2.3 *Vapor retarder*—Proper moisture protection is desirable for any slab on ground where the floor will be covered by tile, wood, carpet, impermeable floor coatings (urethane, epoxy, or acrylic terrazzo), or where the floor will be in contact with any moisture-sensitive equipment or product.

Vapor retarders are often incorrectly referred to as "vapor barriers." A vapor retarder is a material that will effectively minimize the transmission of water vapor from the soil support system through the slab, but is not 100 percent effective in preventing its passage. Although no specific national standard has been established for the effectiveness of these products, it is generally recognized that a vapor retarder is one with a permeance of less than 0.3 US perms (0.2 metric perms) as determined by ASTM E 96.

Although polyethylene film with a thickness of as little as 6 mils (0.15 mm) has been satisfactory as a vapor retarder, the committee strongly recommends that a thickness of not less than 10 mils (0.25 mm) be used. The increase in thickness offers increased resistance to moisture transmission
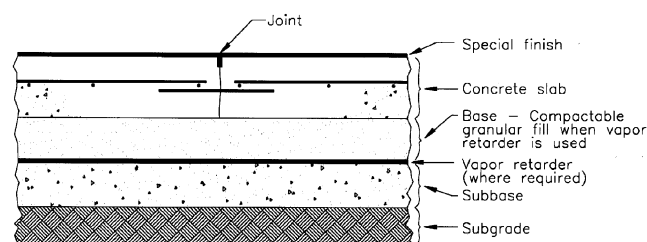

Fig. 3.1—Typical slab on grade

while providing more durability during and after its installation.

A number of products, such as laminated kraft paper with glass fiber reinforcement and reinforced polyethylene film, have previously been incorrectly used as vapor barriers. True vapor barriers are products, such as rugged multiple-reinforced membranes, that have water transmission ratings of 0.00 perms per square foot per hour when tested in accordance with ASTM E 96. Proper performance of a vapor barrier requires that laps in the material be sealed. Refer to manufacturer's recommendations.

Concrete placed in direct contact with a vapor barrier or vapor retarder exhibits significantly larger longitudinal dimensional changes in the first hour after casting than does concrete placed on a granular base[6]; there is also more vertical settlement. Where reinforcing steel is present, settlement cracking over the steel is more likely because of the increased vertical settlement resulting from a longer bleeding period. If the concrete is restrained by connecting members, base friction, or reinforcement, shrinkage cracking is more likely because the concrete placed directly on a vapor barrier or vapor retarder retains more mixing water and thus shrinks more. In one study, high-slump concrete placed directly on plastic sheets exhibited significantly more cracking than concrete placed on a granular base.[7]

Surface crusting is also more likely for slabs placed directly on a vapor barrier or vapor retarder. Concrete that doesn't lose water to the base won't stiffen as rapidly as concrete that does. If the surface crusts over due to drying or to faster setting caused by solar heat gain, the weight of a power float or trowel could crack the crusted surface covering a softer layer of concrete that hasn't lost water. On-site conditions such as low humidity, moderate-to-high winds, use of embedded mineral-aggregate or dry-shake surface hardeners, or a combination of these can aggravate the problem and increase the likelihood of cracking.[6,8]

This Committee recommends that a vapor barrier or vapor retarder be used only when required by the intended use, and that installation be in accordance with Section 4.1.5.

3.2.4 *Temperature and shrinkage reinforcement*—Reinforcement restrains movement resulting from slab shrinkage and can actually increase the number of random cracks experienced, particularly at wider joint spacing (Section 3.2.5.3). Reinforcement in nonstructural slab-on-ground installations is provided primarily to control the width of cracks that occur.[9,10] This reinforcement is normally furnished in the form of deformed steel bars, welded wire reinforcing, steel fibers, or post-tensioning tendons. Combinations of various forms of reinforcement have proved successful. The use of each of these types of reinforcement is discussed in more detail later in this section.

Normally, the amount of reinforcement used in non-structural slabs is too small to have a significant influence on restraining movement resulting from volume changes. Refer to Section 3.2.5 for an expanded discussion of the relationship between joint spacing and reinforcing quantity.

Temperature and shrinkage cracks in unreinforced slabs on ground originate at the surface of the slab and are wider at the surface, narrowing with depth. For maximum effectiveness, temperature and shrinkage reinforcement in slabs on ground should be positioned in the upper third of the slab thickness. The Wire Reinforcement Institute recommends that welded wire reinforcement be placed 2 in. (50 mm) below the slab surface or upper one-third of slab thickness, whichever is closer to the surface.[10] Reinforcement should extend to within 2 in. (50 mm) of the slab edge.

Deformed reinforcing steel or post-tensioning tendons, when used, should be supported and tied together sufficiently to prevent displacement during concrete placing and finishing operations. Chairs with sand plates or precast-concrete bar supports are generally considered to be the most effective method of providing the required support. When precast-concrete bar supports are used, they should be at least 4 in. (100 mm) square at the base, have a compressive strength at least equal to the specified compressive strength of the concrete being placed, and be thick enough to support reinforcing at the proper elevation while maintaining minimum coverage of the reinforcing steel

When welded wire reinforcement is used, its flexibility dictates that the contractor attend closely to establishing and maintaining adequate support of the reinforcement during the concrete placing operations. Welded wire reinforcement should not be laid on the ground and "pulled up" after the concrete has been placed, nor should the mats be "walked in" after placing the concrete. Proper support or support-bar spacing is necessary to maintain welded wire reinforcement at the proper elevation; supports or support bars should be close enough that the welded wire reinforcement cannot be forced out of location by construction foot traffic. Support or support-bar spacing can be increased when heavier gage wires or a double mat of small gage wires is used.

Reinforcing bars or welded wire reinforcement should be discontinued at any joints where the intent of the designer is to let the joint open and to reduce the possibility of shrinkage and temperature cracks in an adjacent panel. Where the reinforcement is carried through the joint, cracks are likely to occur in adjacent panels because of restraint at the joint.[11] When used in sufficient quantity, they will hold out-of-joint cracks tightly closed. Some engineers prefer partial discontinuation of the reinforcement at contraction joints in order to obtain some load transfer capacity without the use of dowel baskets. See Section 3.2.7.

3.2.4.1 *Steel fibers*—In some installations, steel fibers specifically designed for such use can be used with or without conventional shrinkage and temperature reinforcement in slab-on-ground floors. As in the case of conventional reinforcement, steel fibers will not prevent cracking of the concrete. When used in sufficient quantity, they will hold the cracks tightly closed.

3.2.4.2 *Synthetic fibers*—Polypropylene, polyethylene, nylon, and other synthetic fibers can help reduce segregation of the concrete mixture and formation of shrinkage cracks while the concrete is in the plastic state and during the first few hours of curing. As the modulus of elasticity of concrete increases, however, most synthetic fibers at typical dosage

rates recommended by the fiber manufacturers will not provide sufficient restraint to hold cracks tightly closed.

3.2.4.3 *Post-tensioning reinforcement*—The use of steel tendons as reinforcement in lieu of conventional temperature and shrinkage reinforcement allows the contractor to introduce a relatively high compressive stress in the concrete by means of post-tensioning. This compressive stress provides a balance for the crack-producing tensile stresses that develop as the concrete shrinks during the curing process. Stage stressing, or partial tensioning, of the slab on the day following placement can result in a significant reduction of shrinkage cracks. Construction loads on the concrete should be minimized until the slabs are fully stressed.[12,13] For guidelines on installation details, contact a concrete floor specialty contractor who is thoroughly experienced with this type of installation.

3.2.4.4 *Causes of cracking over reinforcement*—Plastic settlement cracking over reinforcement is caused by inadequate compaction of concrete, inadequate concrete cover over reinforcement, use of large-diameter[9] bars, high temperature of bars exposed to direct sunlight, higher-than-required slump in concrete, revibration of the concrete, inadequate curing of the concrete, or a combination of these items.

3.2.5 *Joint design*—Joints are used in slab-on-ground construction to limit the frequency and width of random cracks caused by volume changes. Generally, if limiting the number of joints or increasing the joint spacing can be accomplished without increasing the number of random cracks, floor main-

tenance will be reduced. The layout of joints and joint details should be provided by the designer. If the joint layout is not provided, the contractor should submit a detailed joint layout and placing sequence for approval of the architect/engineer *prior* to proceeding.

As stated in ACI 360R, every effort should be made to avoid tying the slab to any other element of the structure. Restraint from any source, whether internal or external, will increase the potential for random cracking.

Three types of joints are commonly used in concrete slabs on ground: isolation joints, contraction joints, and construction joints. Appropriate locations for isolation joints and contraction joints are shown in Fig. 3.2.5. With the engineer's approval, construction joint and contraction joint details can be interchanged. Refer to ACI 224.3R for an expanded discussion of joints.

Joints in topping slabs should be located directly over joints in the base slab.

3.2.5.1 *Isolation joints*—Isolation joints should be used wherever complete freedom of vertical and horizontal movement is required between the floor and adjoining building elements. Isolation joints should be used at junctions with walls (not requiring lateral restraint from the slab), columns, equipment foundations, footings, or other points of restraint such as drains, manholes, sumps, and stairways.

Isolation joints are formed by inserting preformed joint filler between the floor and the adjacent element. The joint material should extend the full depth of the slab and not protrude above it. Where the joint filler will be objectionably visible, or where there are wet conditions, hygienic or dust-control requirements, the top of the preformed filler can be removed and the joint caulked with an elastomeric sealant. Two methods of producing a relatively uniform depth of joint sealant are as follow:

1. Score both sides of the preformed filler at the depth to be removed by using a saw. Insert the scored filler in the proper location and remove the top section after the concrete hardens by using a screwdriver or similar tool.

2. Cut a strip of wood equal to the desired depth of the joint sealant. Nail the wood strip to the preformed filler and install the assembly in the proper location. Remove the wood strip after the concrete has hardened.

Alternatively, a premolded joint filler with a removable top portion can be used. Refer to Figs. 3.2.5.1.a and 3.2.5.1.b for typical isolation joints around columns. Fig. 3.2.5.1.c shows an isolation joint at an equipment foundation.

Isolation joints for slabs using shrinkage-compensating concrete should be treated as recommended in ACI 223.

3.2.5.2 *Construction joints*—Construction joints are placed in a slab to define the extent of the individual placements, generally in conformity with a predetermined joint layout. If concreting is ever interrupted long enough for the placed concrete to harden, a construction joint should be used. If possible, construction joints should be located 5 ft (1.5 m) or more from any other joint to which they are parallel.

In areas not subjected to traffic, a butt joint is usually adequate. In areas subjected to hard-wheeled traffic and heavy
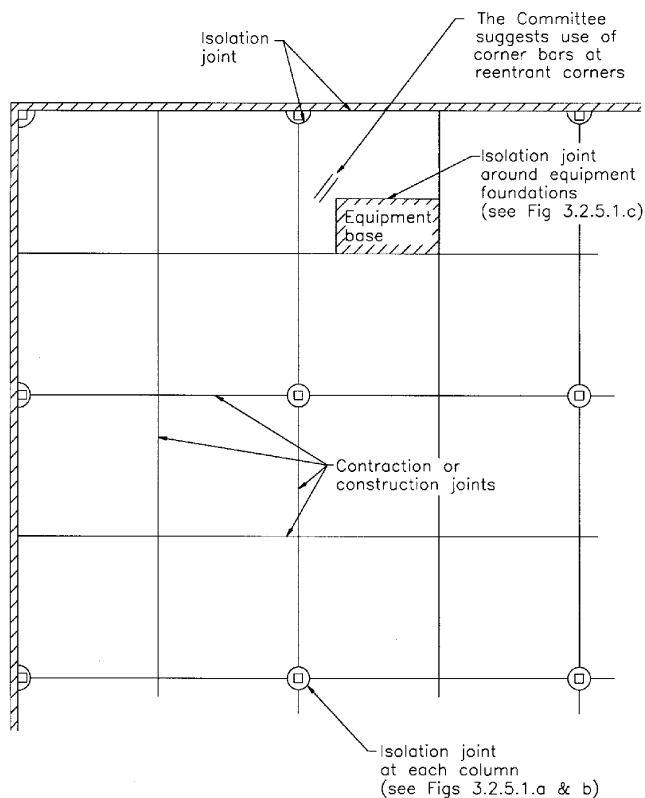
Fig. 3.2.5—Location of joints
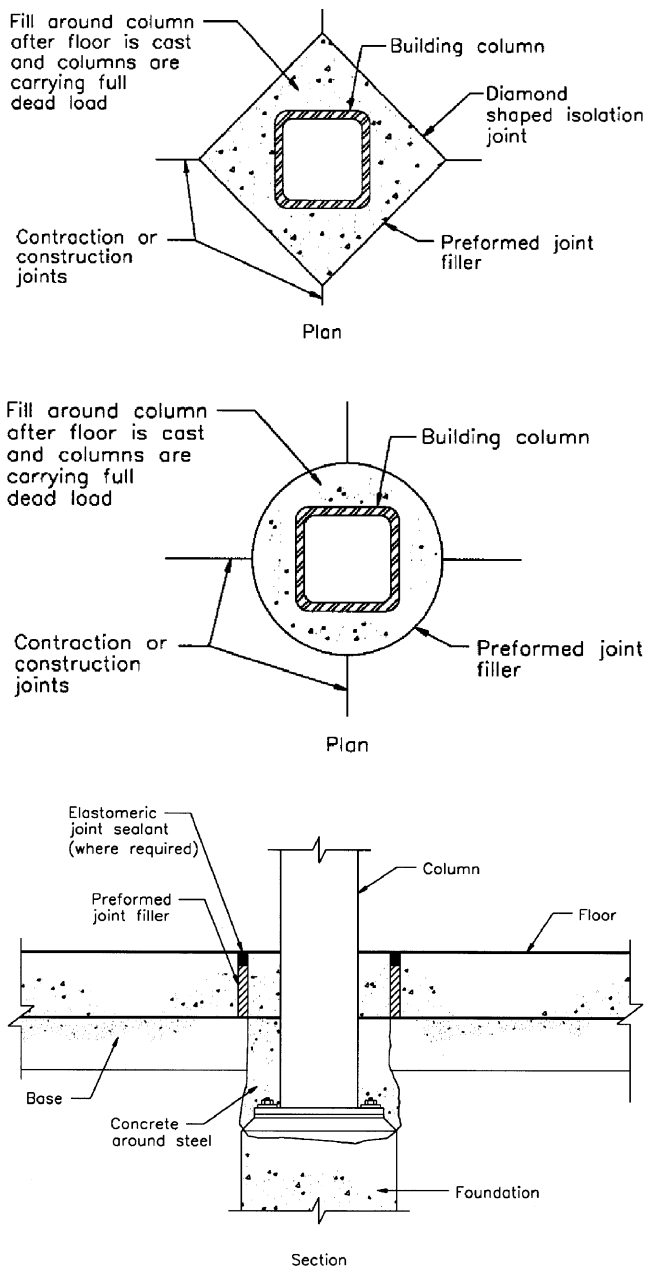
Fig. 3.2.5.1.a—Isolation joint at columns

Fig. 3.2.5.1.b—Isolation joints at columns
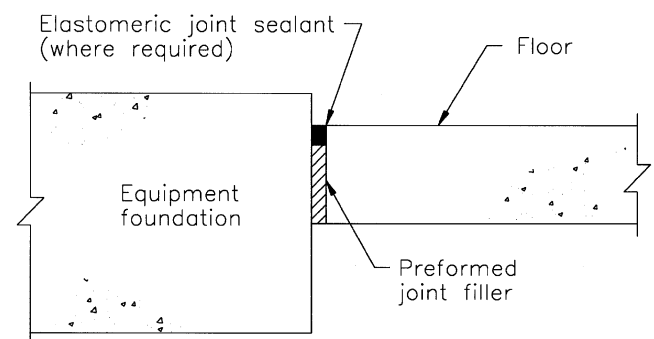
Fig. 3.2.5.1.c—Isolation joint at equipment pad

loadings, or both, joints with dowels are recommended (Fig. 3.2.5.2). A keyed joint can be used for low traffic areas where some load transfer is required. A keyed joint will not provide the same positive load transfer as a properly constructed doweled joint because the male and female key components lose contact when the joint opens due to drying shrinkage (Section 3.2.7).

3.2.5.3 *Contraction joints*—Contraction joints are usually located on column lines, with intermediate joints located at equal spaces between column lines as shown in Fig. 3.2.5. The following factors are normally considered when selecting spacing of contraction joints:

• Method of slab design (refer to ACI 360R)
• Thickness of slab
• Type, amount, and location of reinforcement
• Shrinkage potential of the concrete (cement type and quantity; aggregate size, quantity, and quality; water-cementitious material ratio; type of admixtures; and concrete temperature)
• Base friction
• Floor slab restraints
• Layout of foundations, racks, pits, equipment pads, trenches, and similar floor discontinuities
• Environmental factors such as temperature, wind, and humidity
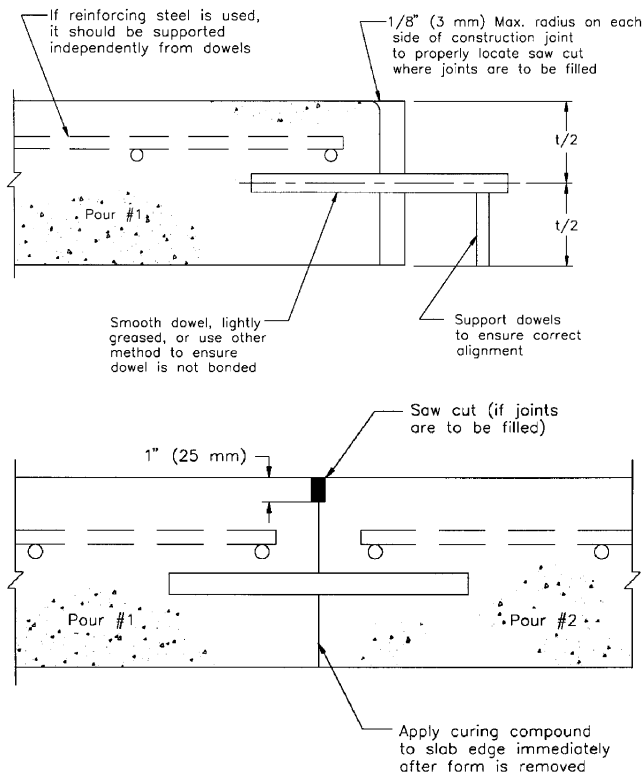
Fig. 3.2.5.2—Doweled construction joint

Fig. 3.2.5.3.a—Types of contraction joints

Fig. 3.2.5.3.b—Joint detail at loading dock

•Methods and quality of concrete curing

As previously indicated, establishing slab joint spacing, thickness, and reinforcement requirements is the responsibility of the designer. The specified joint spacing will be a principal factor dictating both the amount and the character of random cracking to be experienced, so joint spacing should always be carefully selected.

For unreinforced, plain concrete slabs, joint spacings of 24 to 36 times the slab thickness up to a maximum spacing of 18 ft (5.5 m) have generally produced acceptable results. Some random cracking should be expected; a reasonable level might be random cracks occurring in from 0 percent to 3 percent of the floor slab panels formed by saw-cut or construction joints or a combination of both.

Joint spacings can be increased somewhat in nominally reinforced slabs—0.2 percent steel or less placed within 2 in. (50 mm) of the top of the slab—but the incidence of random cracking and curling will increase. Reinforcement will not prevent cracking. However, if the reinforcement is properly sized and located, crack widths should be held to acceptable limits.

Transverse contraction joints can be reduced or eliminated in slabs reinforced with at least 0.5 percent continuous reinforcing steel placed within 2 in. (50 mm) of the top of the slab or upper one-third of slab thickness, whichever is closer to the slab surface. This will typically produce numerous, closely spaced fine cracks throughout the slab.

Joints in either direction can be reduced or completely eliminated by post-tensioning to induce a net compressive force in the slab after all tensioning losses.

The number of joints can also be reduced with the use of shrinkage-compensating concrete. However, the recommendations of ACI 223 should be carefully followed.

Contraction joints should be continuous, not staggered or offset. The aspect ratio of slab panels that are unreinforced, reinforced only for shrinkage and temperature, or made with shrinkage-compensating concrete should be a maximum of 1.5 to 1; however, a ratio of 1 to 1 is preferred. L- and T-shaped panels should be avoided. Fig. 3.2.5.3.a shows various types of contraction joints. Floors around loading docks

have a tendency to crack due to their configuration and re-straints. Fig. 3.2.5.3.b shows one method that can be used to minimize slab cracking at reentrant corners of loading docks.

Plastic or metal inserts are not recommended for creating a contraction joint in any exposed floor surface that will be subjected to wheeled traffic.

3.2.5.4 *Saw cutting joints*—Contraction joints in industrial and commercial floors are usually formed by sawing a continuous slot in the slab to form a weakened plane below which a crack will form (Fig. 3.2.5.3.a). Further details on saw cutting of joints are given in Section 8.3.12.

3.2.6 *Joint filling*—Where there are wet conditions, hygienic and dust-control requirements, or where the floor is subjected to traffic by small, hard-wheeled vehicles such as forklifts, contraction and construction joints should be filled and protected with a semirigid epoxy that gives adequate support to the joint edges and has sufficient resistance to wear. Construction joints should be saw cut 1 in. (25 mm) deep prior to filling. Isolation joints usually are sealed with an elastomeric sealant. Joints should be as narrow as feasible, as long as the joint can be properly filled. Refer to Section 5.12 for a discussion of joint materials and Section 9.10 for installation of joint fillers and sealants.

3.2.7 *Load transfer mechanisms*—Doweled joints (Figs. 3.2.5.2 and 3.2.7.a) are recommended when positive load transfer is required, unless post-tensioning is provided across the joint. Dowels force concrete on both sides of a joint to deflect equally when subjected to a load, and help prevent damage to an exposed corner when the joint is subjected to hard-wheeled traffic. Table 3.2.7 provides recommended dowel sizes and spacing. For dowels to be effective, they should be smooth, aligned and supported so they will remain parallel in both the horizontal and the vertical planes during the placing and finishing operation. Properly-aligned, smooth dowels allow the joint to open as concrete shrinks. Dowel baskets (Fig. 3.2.7.b) should be used to maintain alignment of dowels. Dowels should be placed no closer than 12 in. (300 mm) from the intersection of any joints.

As indicated in ACI 223, square dowels cushioned on the vertical sides by a compressible material to permit movement parallel and perpendicular to the joint are available. This type of dowel is useful where the joint must have load-transfer capability while allowing some differential move-ment in the direction of the joint, such as might be necessary in post-tensioned slabs on ground.[14]

In saw-cut contraction joints, aggregate interlock should not be relied upon for effective load transfer for wheeled traffic if the expected crack width exceeds 0.035 in. (0.9 mm).[15]

Deformed reinforcing bars should not be used across contraction joints or construction joints because they restrain joints from opening as the slab shrinks during drying. Continuation of a part of the slab reinforcing through contraction joints can provide some load transfer capability without using dowels, but increases the probability of out-of-joint cracking.

Keyed joints are not recommended in slabs on ground where heavy traffic is anticipated as they do not provide effective load transfer. When the concrete shrinks, the keys and keyways do not retain contact and do not share the load between panels; this can eventually cause a breakdown of the concrete edges of the joint.

For long post-tensioned floor strips, care should be taken to accommodate significant slab movements. In most instances, post-tensioned slab joints are associated with a jacking gap. The filling of jacking gaps should be delayed as long as possible in order to accommodate shrinkage and creep. In traffic areas, armor plating of the joint edges is recommended. Fig. 3.2.7.c depicts a doweled joint detail at a jacking gap in a post-tensioned slab.[13,16]

3.3—Suspended slabs

3.3.1 *Required design elements*—In addition to many of the items listed in Section 1.1.2, the following items specifically impacting construction of suspended slabs should be included in the contract documents prepared by the engineer of record:

- Frame geometry (member size and spacing)
- Reinforcement (type, size, location, and method of support)
- Shear connectors, if required
- Construction joint location
- Metal deck (type, depth, and gage), if required
- Shoring, if required
- Tolerances (forms, structural steel, reinforcement, and concrete)

3.3.2 *Suspended slab types*—In general, suspended floor systems fall into three main categories: (1) slabs with remov-

Table 3.2.7— Dowel size and spacing

Slab depth	Dowel diameter	Total dowel length*	Dowel spacing, center to center
in.	in.	in.	in.
5-6	$^3/_4$	16	12
7-8	1	18	12
9-11	$1^1/_4$	18	12
mm	mm	mm	mm
125-500	19	400	300
175-200	25	450	300
225-275	30	450	300

*Allowance made for joint openings, minor errors in positioning dowels.
Note: Dowels must be carefully aligned and supported during concrete operations. Misaligned dowels cause cracking.

able forms, (2) slabs on metal decking, and (3) topping slabs on precast concrete.

Design requirements for cast-in-place concrete suspended floor systems are covered by ACI 318 and ACI 421.1R. Refer to these documents to obtain design parameters for various cast-in-place systems. Slabs on metal decking and topping slabs on precast concrete are hybrid systems that involve design requirements established by ANSI, ASCE, the American Institute of Steel Construction, and the Precast/Prestressed Concrete Institute, as well as those established by ACI 117.
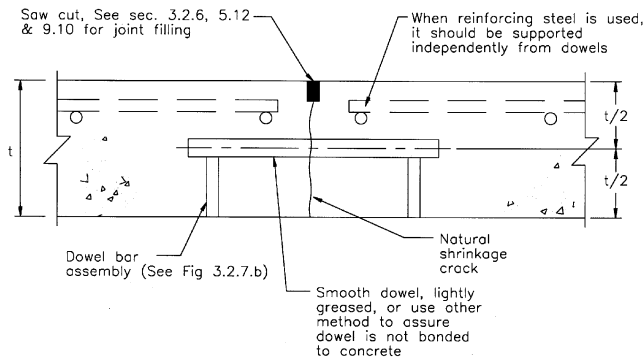
Fig. 3.2.7.a—Doweled contraction joint
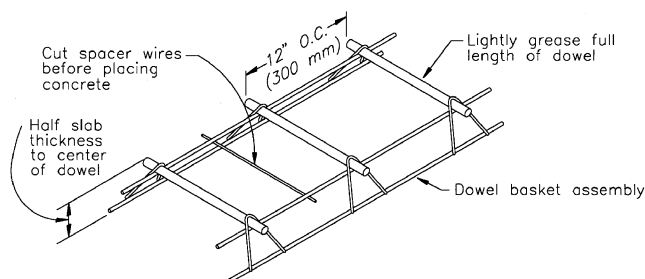
Fig. 3.2.7.b—Dowel basket assembly
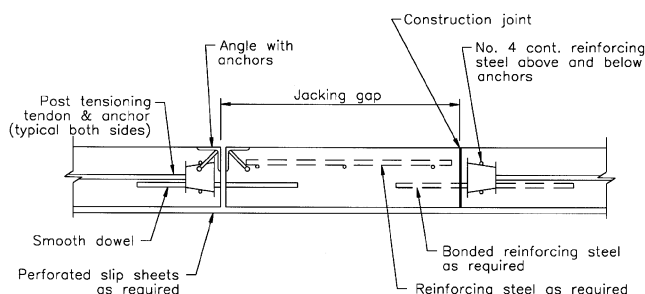
Fig. 3.2.7.c—Joint detail for post-tensioned slab

Levelness of suspended slabs is dependent on accuracy of formwork and strikeoff, but is further influenced (especially in the case of slabs on metal decking) by behavior of the structural frame during and after completion of construction. Each type of structural frame behaves somewhat differently; it is important that the contractor recognize those differences and plan accordingly.

The presence of camber in some floor members and the ACI 117 limitation on variation in slab thickness dictate that concrete be placed to a uniform thickness over the supporting steel. *When placing slabs on metal decking, the contractor is cautioned that deflections of the structural steel members can vary from those anticipated by the design engineer. Achieving a level deflected surface can require increasing the slab thickness more than $^3/_8$ in. (10 mm) in local areas. The committee recommends that placement procedures and the basis for acceptance of the levelness of a completed floor surface be established and agreed upon by key parties prior to beginning suspended floor construction.* [17]

3.3.3 *Slabs with removable forms*—Cast-in-place concrete construction can be either post-tensioned or conventionally reinforced. Both of these systems are supported during initial concrete placement, and they will move when supporting shores are removed.

Post-tensioned systems are normally used by the designer when larger spans are necessary or when the structural system should be shallow for the spans involved. Post-tensioned systems use high-tensile steel tendons that are stretched beyond their initial length using a hydraulic jack designed for that purpose. The tension produced by this stretching operation has the end result of compressing the concrete. The magnitude of floor slab deflection after supports are removed is less than that of comparable floors reinforced with conventional deformed reinforcing steel. At times, dead load deflection is entirely eliminated by the use of post-tensioning.

The deformed reinforcing steel in conventionally reinforced floor systems will start working as the floor deflects. The magnitude of deflection is dependent on a number of variables such as span, depth of structure, age at the time forms are stripped, concrete strength, and amount of reinforcement. In locations where the anticipated dead load deflection of a member is deemed excessive by the design engineer, an initial camber, generally $^1/_2$ in. (13 mm) or more, can be required. The amount of camber is determined by the engineer based on an assessment of the impact of the variables just discussed. Ideally, the cambered parts of the floor system will deflect down to a level position after removal of the supporting shores.

3.3.4 *Slabs on metal deck*—Construction of slabs on metal deck involves the use of a concrete slab and a supporting platform consisting of structural steel and metal deck. The structural steel for this type of construction can be shored or unshored at the time of concrete placement, and the metal deck serves as a stay-in-place form for the concrete slab. This construction can be composite or noncomposite.

The supporting steel platform for slabs on metal deck is seldom level. Variation in elevations at which steel beams connect to columns and the presence of camber in some floor

members combine to create variations in the initial elevation of steel members. Regardless of the initial levelness of the steel frame, unshored frames will deflect during concrete placement. These factors make the use of a laser or similar instrument impractical for the purpose of establishing a uniform elevation for strikeoff of the concrete surface of a slab on metal deck. The presence of camber in some floor members and the ACI 117 limitation on variation in slab thickness dictate that concrete be placed to a uniform thickness over the supporting steel.

3.3.4.1 *Composite slabs on metal deck*—In composite construction, the composite section (concrete slab and steel beams) will work together to support any loads placed on the floor surface after the concrete has hardened. Composite behavior is normally developed through the use of shear connectors welded to the structural steel beam. These shear connectors physically connect the concrete slab to the beam and engage the concrete slab within a few feet of the steel beam; the resulting load-carrying element is configured much like a capital "T." The steel beam forms the stem of the "T," and the floor slab forms the cross-bar. It is important that construction joints be located far enough from structural steel beams that they parallel to eliminate their impact on composite behavior. Questions about the location of construction joints should be referred to the engineer of record on the project.

Unshored composite construction is the more common method used by designers because it is generally less expensive than shored construction. In unshored construction, the structural steel beams are sometimes cambered slightly during the fabrication process. This camber is intended to offset the anticipated deflection of that member under the weight of concrete. Ideally, after concrete has been placed and the system has deflected, the resulting floor surface will be level.

Shored composite concrete slabs on metal deck are similar to slabs with removable forms, in that both are supported until the concrete has been placed and reaches the required strength. Structural steel floor framing members for shored composite slabs on metal deck are usually lighter and have less camber than those used for unshored construction with similar column spacings and floor loadings. One major concern with shored composite construction is the tendency for cracks wider than $1/8$ in. (3 mm) to form in the concrete slab when the supporting shores are removed. These cracks do not normally impair the structural capacity of the floor, but can become a severe aesthetic problem. *The contractor is cautioned that this issue and any measures taken by the designer to avoid the formation of cracks should be addressed to the satisfaction of key parties prior to beginning suspended floor construction.*

3.3.4.2 *Noncomposite slabs on metal deck*—In noncomposite construction, the slab and supporting structural steel work independently to support loads imposed after hardening of the concrete slab.

3.3.5 *Topping slabs on precast concrete*—A cast-in-place concrete topping on precast prestressed concrete units involves the use of precast elements as a combination form and load-carrying element for the floor system. The cast-in-place

portion of the system consists of a topping of some specified thickness placed on top of the precast units. The topping can be composite or noncomposite. In either case, added deflection of precast units under the weight of the topping slab is normally minor, so the finished surface will tend to follow the surface topography established by the supporting precast units. The camber in precast members, if they are prestressed, can change with time as a result of concrete creep. Depending on the length of time between casting of precast units and erection, this potential variation in camber of similar members can create significant challenges for the contractor. Care should be taken in the scheduling of such operations to minimize the potential impact of these variations. Precast members are less flexible and adaptable to changes or modifications that can be required on the jobsite than are the previously discussed systems.

3.3.6 *Reinforcement*—For cast-in-place concrete suspended slabs, reinforcing steel location will vary as dictated by the contract documents. Post-tensioning reinforcement, when used, is enclosed in a plastic or metal sleeve and is stretched beyond its initial length by means of a hydraulic jack after the concrete reaches sufficient compressive strength. Elongation and subsequent anchoring of the ends of post-tensioning tendons results in transfer of compressive force to the concrete. See references for installation details.

For slabs on metal deck, reinforcement is normally provided by deformed reinforcing steel, welded wire reinforcement, steel fibers, or a combination thereof.

3.3.7 *Construction joints*—The engineer of record should provide criteria for location of construction joints in suspended slabs. Following is a general discussion of criteria that can influence these decisions.

3.3.7.1 *Slabs on removable forms*—Construction joints can introduce weak vertical planes in an otherwise monolithic concrete member, so they should be located where shear stresses are low. Under most gravity load conditions, shear stresses in flexural members are low in the middle of the span. ACI 318 requires that construction joints in floors be located within the middle third of spans of slabs, beams and primary beams. Joints in girders should be offset a minimum distance of two times the width of any intersecting beams.

3.3.7.2 *Composite slabs on metal deck*—An important consideration when locating construction joints in composite slabs on metal deck is that the joint location can influence deflection of the floor framing near the joint. A composite member (steel beam and hardened concrete slab working together) is stiffer, and deflects less, than a non-composite member (steel beam acting alone). Most composite slabs on metal deck are placed on an unshored structural steel floor frame. Often, structural steel members have fabricated camber to offset anticipated noncomposite deflection resulting from concrete placement; during placement of the concrete, the structural steel deflects a small amount. After hardening of the concrete, however, the composite member deflects much less than a comparable noncomposite beam or primary beam.

Following are general guidelines for locating construction joints in composite slabs on metal deck.

1. For slabs that span in one direction between primary beams, locate construction joints that parallel secondary beams a sufficient distance from the structural steel member to allow full flange width to be developed. For slabs that span between secondary beams, the construction joint should normally be located near midspan of the slab between beams.

2. Locate construction joints that parallel primary beams, and cross secondary beams, near the primary beam. It is important, however, to allow sufficient distance for development of the primary beam flange width. Placing the construction joint a distance of 4 ft (1.2 m) from the primary beam is usually sufficient for this purpose. This location allows nearly the full dead load from concrete placement to be applied to secondary beams on both sides of the primary beam at one time.

If the primary beam is not cambered, it might be best to consider including the primary beam in the initial placement. Dead load deflection will be reduced because a composite section will be supporting the second concrete placement at that construction joint. If the primary beam is cambered, it should be included in the second placement at the construction joint. This will allow full dead load from concrete to be present prior to hardening of concrete at the primary beam.

3. Construction joints that cross primary beams should be located near a support at one end of the primary beam. This will allow full dead load from concrete to be present prior to hardening of concrete at the primary beam.

3.3.7.3 *Noncomposite slabs on metal deck*—The location of construction joints in noncomposite slabs on metal deck should follow the same general guidelines discussed for slabs on removable forms in Section 3.3.6.1.

3.3.7.4 *Topping slabs on precast concrete*—Construction joints in topping slabs on precast concrete should be located over joints in the supporting precast concrete.

3.3.8 *Cracks in slabs on metal deck*—Cracks often develop in slabs on metal deck. These cracks can result from drying shrinkage and thermal contraction or variations in flexibility of the supporting structural steel and metal deck. In a composite floor framing system, primary beams are the stiffest elements and generally deflect less than secondary beams. The most flexible part of the floor framing assembly is the metal deck, which often is designed for strength and with little thought to its flexibility.

If the metal deck is flexible, vibration as a result of power floating and power troweling operations can produce cracking over the structural steel beams during concrete finishing operations. As the concrete cures and shrinks, these cracks will open wide if not restrained by reinforcing steel, usually welded wire reinforcement, located near the top surface of the slab.

3.4—Miscellaneous details

3.4.1 *Heating ducts*—Heating ducts embedded in a concrete slab can be of metal, rigid plastic, or wax-impregnated cardboard. Ducts with waterproof joints are recommended. When metal ducts are used, calcium chloride should not be used in the concrete. Refer to Section 5.6.3 for a discussion on chlorides in concrete and Section 4.5.2 for installation of heating ducts.

3.4.2 *Edge insulation*—Edge insulation for slabs on ground is desirable in most heated buildings. The insulation should be in accordance with ASHRAE 90.1. It should not absorb moisture and should be resistant to fungus, rot, and insect damage; it should not be easily compressed.

Insulation should preferably be placed vertically on the inside of the foundation. It can also be placed in an L-shape adjacent to the inside of the foundation and under the edge of the slab. In either case, the installation should extend a total distance of 24 in. (600 mm).

3.4.3 *Radiant heating: piped liquids*—Slabs can be heated by circulating heated liquids through embedded piping. Ferrous, copper, or plastic pipe is generally used, with about 2 in. (50 mm) of concrete [not less than 1 in. (25 mm)] under the pipe and with 2 to 3 in. (50 to 75 mm) of concrete cover over the pipe. The slab is usually monolithic, and the concrete is placed around the piping, which is fixed in place. Two-course slab construction has also been used, wherein the pipe is laid, connected, and pressure tested for tightness on a hardened concrete base course. Too often, however, the resulting cold joint is a source of later trouble.

Insulating concrete made with vermiculite or perlite aggregate, or cellular foam concrete can be used as a subfloor. The piping should not rest directly on this or any other base material. Supports for piping during concreting should be inorganic and nonabsorbent; precast concrete bar supports (Section 3.2.4) are preferred to random lengths of pipe for use as supports and spacers. Wood, brick, or fragments of concrete or concrete masonry should not be used.

Sloping of the slab, where possible, can simplify sloping of the pipe. Reinforcement, such as welded wire reinforcement, should be used in the concrete over the piping. Where pipe passes through a contraction joint or construction joint, provision should be made for possible movement across the joint. The piping should also be protected from possible corrosion induced by chemicals entering the joint. The piping should be pressure-tested before placing concrete and air pressure (not water pressure) should be maintained in the pipe during concreting operations. After concreting, the slab should not be heated until curing of the concrete is complete. The building owner should be warned to warm the slabs gradually, using lukewarm liquid in the system, to prevent cracking of the cold concrete.

3.4.4 *Radiant heating: electrical*—In some electrical radiant heating systems, insulated electrical cables are laid singly in place within the concrete or fastened together on transverse straps to form a mat. One system employs cable fastened to galvanized wire sheets or hardware cloth. The cables are embedded 1 in. to 3 in. (25 mm to 75 mm) below the concrete surface, depending on their size and operating temperature. In most systems the wires, cables, or mats are laid over a bottom course of unhardened concrete, and the top course is placed immediately over this assemblage with little lapse of time, thus avoiding the creation of a horizontal cold joint.[18]

Calcium chloride should not be used where copper or aluminum wiring is embedded in the concrete; damage to insulation and subsequent contact between the exposed wiring and reinforcing steel will cause corrosion. If admixtures are used, their chloride contents should comply with the limits recommended by ACI 222R.

3.4.5 *Snow-melting*—Systems for melting snow and ice can be used in loading platforms or floor areas subjected to snow and ice. The concrete should be air-entrained for freeze-thaw resistance. Concrete surfaces should have a pitch of $^1/_4$ in. per ft (20 mm per m) to prevent puddles from collecting. Piping systems should contain a suitable liquid heat-transfer medium that does not freeze at the lowest temperature anticipated. Calcium chloride should not be used (Section 5.6.3). Experience has shown these systems to demand high energy consumption while displaying a high potential for failure and thermal cracking. The most successful applications appear to have been at parking garage entrances.

Some electrical systems are in use. These internally heated snow-melting systems have not been totally satisfactory.

3.4.6 *Pipe and conduit*—Water pipe and electrical conduit, if embedded in the floor, should have at least $1^1/_2$ in. (38 mm) of concrete cover, both on top and bottom.

3.4.7 *Slab embedments in harsh environments*—Care should be exercised in using heating, snow-melting, water, or electrical systems embedded in slabs exposed to harsh environments, such as parking garages in northern climates, and marine structures. Embedded systems can accelerate deterioration by increasing seepage of saltwater through the slab or by forming electrical corrosion circuits with reinforcing steel. If concrete deterioration occurs, the continuity and effective functioning of embedded systems are invariably disrupted.

CHAPTER 4—SITE PREPARATION AND PLACING ENVIRONMENT

4.1—Soil support system preparation

The soil support system should be well drained and provide adequate and uniform load-bearing support.

The ability of a slab to take loads depends on the integrity of *both* the slab and full soil support system. As a result, it is essential that the full soil support system be tested or thoroughly evaluated *before* the slab is placed upon it.[19]

The in-place density of the subgrade, subbase (if used), and base (Fig. 3.1) should be at least the minimum required by the specifications, and the base should be free of frost before concrete placing begins and able to support construction traffic such as loaded truck mixers.

The base should normally be dry at the time of concreting. However, if protection from the sun and wind cannot be provided as mentioned in Section 4.6, or if the concrete is placed in hot, dry conditions, the base should be lightly dampened with water in advance of concreting. There should be no free water standing on the base, nor should there be any muddy or soft spots, when the concrete is placed (Sections 4.1.1 and 4.1.4).

4.1.1 *Proof-rolling*—Proof-rolling is one of the most effective ways to determine if the full soil support system is adequate to provide a uniformly stable and adequate bearing support during and after construction. If applicable, this process should be implemented after completion of the rough grading and if required can be repeated prior to the placement of the slab (Fig. 4.1.1).

Proof-rolling, observed and evaluated by the engineer or the engineer's representative, should be accomplished by a loaded tandem axle dump truck, a loaded truck mixer, roller, or equivalent. In any case, multiple passes should be made using a preestablished grid pattern.

If rutting or pumping is evident at any time during the preparation of the subgrade, subbase, or baserolling, corrective action should be taken.

"Rutting" normally occurs when the surface of the base or subbase is wet and the underlying soils (subgrade) are firm. "Pumping" normally occurs when the surface of the base or subbase is dry and the underlying soils are wet. Any depression in the surface deeper than $^1/_2$ in. (13 mm) should be repaired. Repair should include, but not be limited to, raking smooth or compacting with suitable compaction equipment.

4.1.2 *Subgrade tolerance*—The necessary grading of the subgrade, often referred to as "rough grading," should conform to a tolerance of + 0 in./- $1^1/_2$ in. (+ 0 mm/- 38 mm). Compliance should be confirmed prior to removal of excavation equipment. A rod and level survey should be performed; measurements should be taken at 20-ft (6-m) intervals in each direction.

4.1.3 *Base tolerance*—Base tolerances, often referred to as "fine grading," should conform to a tolerance of + 0 in./- 1 in. (+ 0 mm/- 25 mm) for floor Classes 1 through 3 and + 0 in./- $^3/_4$ in. (+ 0 mm/-19 mm) for floor Classes 4 through 9 when measured from bottom of slab elevation. Compliance with these fine-grade values should be based on the measurements of individual floor sections or placements. A rod and level survey should be performed; measurements should be taken at 20-ft (6-m) intervals in each direction.

Fig. 4.1.1—Proofrolling by loaded ready mix truck

Table 5.4.1— General guide for preferred grading of fine aggregates for floor concrete

Sieve designations		Percent passing		
Standard	Alternative	Normal weight aggregate	Light-weight aggregate	Heavy-duty toppings, Class 7 floors
9.5 mm	$^3/_8$ in.	100	100	95
4.75 mm	No. 4	85-100	85-100	95-100
2.36 mm	No. 8	80-90	—	65-80
1.18 mm	No. 16	50-75	40-80	45-65
600 μ m	No. 30	30-50	30-65	25-45
300 μ m	No. 50	10-20	10-35	5-15
150 μ m	No. 100	2-5	5-20	0-5

4.1.4 *Base material*—Use of the proper materials is essential in order to achieve the tolerances suggested in Section 4.1.3. The base material should be a compactible, easy-to-trim, granular fill that will remain stable and support construction traffic. The tire of a loaded concrete truck mixer should not penetrate the surface more than $^1/_2$ in. (13 mm) when driven across the base. The use of so-called cushion sand or clean sand with uniform particle size, such as concrete sand meeting ASTM C33, will not be adequate. This type of sand will be difficult, if not impossible, to compact and maintain until concrete placement is complete.

A clean, fine-graded material with at least 10 percent to 30 percent of particles passing a No. 100 (150 μm) sieve but not contaminated with clay, silt, or organic material is recommended. Manufactured sand from a rock-crushing operation works well; the jagged slivers tend to interlock and stabilize the material when compacted. It is important that the material have a uniform distribution of particle sizes ranging from No. 4 (4.75 mm) through the No. 200 (80 μm) sieve. See ASTM C33, Table 1, for limitation of deleterious material finer than No. 200 (80 μm) sieve. Unwashed size No. 10 per ASTM D 448 works well.

4.1.5 *Vapor barrier/vapor retarder*—If a vapor barrier or vapor retarder is required due to local conditions, these products should be placed under a minimum of 4 in. (100 mm) of trimable, compactible, granular fill *(not sand)*. A so-called "crusher run" material, usually graded from $1^1/_2$ in. to 2 in. (38 mm to 50 mm) down to rock dust, is suitable. Following compaction, the surface can be choked off with a fine-grade material (Section 4.1.4) to reduce friction between the base material and the slab.

If it is not practical to install a crusher-run material, the vapor barrier/retarder should be covered with at least 3 in. (75 mm) of fine-graded material, such as crusher fines or manufactured sand (Section 4.1.4). The granular fill, as well as the fine-graded material, should have sufficient moisture content to be compactible, but still be dry enough at the time of concrete placement to act as a "blotter" (Section 4.1).

If a vapor barrier/retarder is to be placed over a rough granular fill, a thin layer of approximately $^1/_2$ in. (13 mm) of fine-graded material should be rolled or compacted over the fill prior to installation of the vapor barrier/retarder to reduce the possibility of puncture (Section 4.1.4). Vapor barriers/retarders should be overlapped 6 in. (150 mm) at the joints and

carefully fitted around service openings. See Section 3.2.3 for more information on vapor barriers/retarders for slabs on ground.

4.2—Suspended slabs

Prior to concrete placement, bottom-of-slab elevation as well as the elevation of reinforcing steel and any embedments should be confirmed. Forms that are too high can often force reinforcement above the desired elevation for the slab surface. Screed rails or guides should be set at elevations that will accommodate initial movement of the forms as they are loaded. Screed rails may also be set at elevations that will offset downward deflection of the structure following concrete placement (Section 3.3).

4.3—Bulkheads

Bulkheads can be wood, metal, or precast concrete[20]; they should be placed at the proper elevation with stakes and necessary support required to keep the bulkheads straight, true, and firm during the entire placing and finishing procedure. Keyways are not recommended. However, if specified, small wood or metal keys should be attached to the inside of the form.

When it is necessary to set bulkheads on insulation material, such as in cold storage or freezer rooms, extra attention should be given to keeping the forms secure during the placing and finishing process. The insulation material should not be punctured by stakes or pins. It may be necessary to place sand bags on top of form supports to ensure stability during concrete placement.

Circular or square forms can be used to isolate the columns. Square forms should be rotated 45 deg (Fig. 3.2.5.1.a) or installed in a pin-wheel configuration as indicated in Fig. 3.2.5.1.b. Walls, footings, and other elements of the structure should be isolated from the floors. Asphalt-impregnated sheet or other suitable preformed compressible joint material (ACI 504R) should be used. These joint materials should never be used as freestanding forms at construction joints or column block outs, but should be installed after the original forms have been removed. After removal of forms around columns, preformed joint materials should be placed at the joint to the level of the floor surface, and the intervening area concreted and finished. These preformed joint materials can be placed at the proper elevation to serve as screed guides

during the concreting operations. The preformed joint material should be of the type specified and should conform to one of the following specifications, depending upon the conditions of its use: ASTM D 994, D 1751, or D 1752.

4.4—Setting screed guides

The screed guides can be 2-in.-thick (50-mm) lumber, pieces of pipe, T bars, or rails, the tops of which are set to the finished concrete grade without changing the design elevation of the reinforcing steel. Each type should have a tight-radius edge. If the wet-screed approach is used to establish concrete grade, the finished floor elevation for a slab on ground may be laid out by driving removable grade stakes into the subgrade at predetermined intervals that are appropriate for the width of placement strips being installed. The tops of these stakes should be set to the required concrete grade.

4.4.1 *Establishing grades for adequate drainage on the slab surface*—When positive drainage is desired, the forms and screed guides should be set to provide for a minimum slope of $^1/_4$ in. per ft (20 mm/m) to prevent ponding. Positive drainage should always be provided for exterior slabs and can be desirable for some interior slabs.

4.5—Installation of auxiliary materials

4.5.1 *Edge insulation*—Insulation (Section 3.4.2) should preferably be placed vertically on the inside of the foundation. It can also be placed in an inverted L-shape adjacent to the foundation and under the edge of the slab.

4.5.2 *Heating ducts*—Metal, rigid plastic, or wax-impregnated cardboard ducts with watertight joints are recommended; they can be set on a sand-leveling bed and back-filled with sand to the underside of the slab. Precautions should be taken to ensure that the position of the ducts is not disturbed during concreting, and that they are adequately protected from corrosion or deterioration.

If the ducts to be used are not waterproof, they should be completely encased in at least 2 in. (50 mm) of concrete to prevent the entrance of moisture.

4.6—Concrete placement conditions

When slabs are placed on grade, there should be no more than 30 F (17 C)—ideally, 20 F (11 C)—difference between the temperature of the base and concrete at the time of placement.

Floor slab installations should be made in a controlled environment where possible. Protection from the sun and wind is crucial to the placing and finishing process. The roof of the structure should be waterproof, and the walls should be completely up. The site should provide easy access for concrete trucks and other necessary materials and suppliers. The site should be adequately lighted and ventilated. Temperatures inside the building should be maintained above 50 F (10 C) while placing, finishing, and curing the concrete. If heaters are required, they should be vented to the outside.[21] Salamanders or other open flame heaters that might cause carbonation of the concrete surface should not be used. When installation procedures are carried out each day under the

same predictable conditions, the resulting floors are significantly superior to those floors installed under varying or poor environmental conditions. Also, see Sections 9.5.1 and 9.5.2 for cold and hot weather considerations.

CHAPTER 5—MATERIALS

5.1—Introduction

Concrete ingredients meeting the same ASTM standards can affect the concrete very differently. These standards offer a wide window of acceptance.[22] It is, therefore, recommended that the specific characteristics of ingredients be investigated prior to the preparation of mixture proportions for floors and slabs.

5.2—Concrete

Since minimizing shrinkage is of prime importance, special attention should be given to selecting the best possible concrete mixture proportions. The shrinkage characteristics of a concrete mixture can be determined by ASTM C 157. Should it be necessary to determine if a proposed concrete mixture has other than normal shrinkage, approximately .05 percent, the proposed concrete mixture should be compared to the specified or a reference concrete mixture using ASTM C 157. It is essential that the concrete used in these tests be made with the same materials that will be used in the actual construction.

Approval of a concrete mixture for use in a floor should not be solely based on its meeting the specified compressive strength related to standard laboratory cured cylinders. The portland cement content, and the content of other cementitious products if used, should be sufficient to allow satisfactory finishability. The setting characteristics of the concrete should be relatively predictable. It should be verified that the concrete will not experience excessive retardation, differential set time, or surface crusting difficulties under the conditions of temperature and humidity expected on the project. Some admixture-cement combinations can cause these difficulties, particularly when multiple admixtures are used. Since there is not a generally-recognized procedure for establishing these performance characteristics, the committee recommends placement of a sample floor slab as indicated in Section 6.2.4. Floor concrete requirements differ from those of other concrete used in the structure. Project requirements should be reviewed thoroughly prior to mixture proportioning. If possible, the concrete contractor should have the opportunity to review the proposed mixture proportions, and to prepare a sample placement to verify the workability, finishability, and setting time for the proposed usage.

5.3—Portland cement

5.3.1—Concrete floors can incorporate a variety of portland cements that meet ASTM Specifications C 150, C 595, C 845, and C 1157.

Of the four cements used in floors and slabs described in ASTM C 150, Type I is the most common, and it is used when the special properties of another type are not required. Type II is also for general use, especially when moderate sul-

fate resistance or moderate heat of hydration is desired. Type III is used when high early strength is desired. Type V is used where high sulfate resistance is required.

If air-entrained concrete is required, air-entrainment should be obtained with an admixture, rather than by using an air-entraining cement; this allows for better control of air content.

5.3.2 *Blended hydraulic cements*—Blended hydraulic cements are produced by intimately and uniformly blending two or more types of fine materials, such as portland cement, ground granulated blast furnace slag, fly ash and other pozzolans, hydrated lime, and preblended cement combinations of these materials.

There are six recognized classes of blended cements that conform with ASTM C 595: Type IS portland blast-furnace slag cement; Type IP and P portland-pozzolan cements; Type I (PM) pozzolan-modified portland cement; Type S slag cement; and Type I (SM) slag-modified portland cement. However, Types P and S are normally not available for use in general concrete construction. It is strongly recommended that the manufacturers of these cements be contacted for information regarding the specific product and the impact its use will have on setting time, strength, water demand, and shrinkage of concrete proposed for the project under anticipated field conditions. Conformance to the requirements of ASTM C 150 does not impose sufficient restrictions on the cement to be used; if the 28-day design strength is achieved, but shrinkage is excessive and retardation is significant, the cement may not be suitable for the project.

ASTM C 1157 is a performance specification that establishes physical requirements for six types of blended cements mirroring the attributes of ASTM C 150 cement types.

For information on pozzolans used as cement replacements or cementitious additions, see Section 5.6.5.

5.3.3 *Expansive cements*—Types K, M, and S are expansive cements meeting ASTM C 845 specifications that are used in shrinkage-compensating concrete floors. See ACI 223 for specific details on shrinkage-compensating concrete floors. Shrinkage-compensating concrete can also be made by adding an expansive admixture as discussed in Section 5.6.4.

5.4—Aggregates

Aggregates should conform to ASTM C 33 or to ASTM C 330. These specifications are satisfactory for most Class 1, 2, 3, 4, 5, and 6 floors. Additional limitations on grading and quality can be required for the surface courses of heavy-duty Class 7 and 8 floors.

Although these ASTM standards set guidelines for source materials, they do not establish combined gradation requirements for the aggregate used in concrete floors A uniform gradation is necessary to produce a desirable matrix while reducing water demand of the concrete mixture and reducing the amount of cement paste required to coat the aggregate.[23]

5.4.1 *Fine aggregate grading*—Although ASTM C 33 and C 330 are acceptable specifications, Table 5.4.1 contains preferred grading specifications for the toppings for Class 7 floors. The amount of material passing the No. 50 and 100 sieves (300 and 150 μm) should be limited as indicated for heavy-duty floor toppings for Class 7. However, when fine aggregates contain minimum percentages of material passing the No. 50 and 100 sieves (300 and 150 μm), the likelihood of excessive bleeding is increased and limitations on water content of the mixture become increasingly important. Natural sand is preferred to manufactured sand; the gradation indicated in Table 5.4.1 will minimize water demand.

5.4.2 *Coarse aggregate grading*—The maximum size of coarse aggregate should not exceed three-fourths the minimum clear spacing of the reinforcing bars in structural floors, nor one-third the thickness of nonreinforced slabs. In general, natural aggregate larger than $1^{1}/_{2}$ in. (38 mm) or lightweight aggregate larger than 1 in. (25 mm), is not used. Although the use of large aggregate is generally desired for lower water demand and shrinkage reduction, it is important to recognize the overall gradation of all the aggregate (Section 5.1). When aggregate sizes larger than 1 in. (25 mm) are used, the coarse aggregate can be batched as two sizes to prevent segregation. Drying shrinkage can be minimized by the use of the largest practical size coarse aggregate. However, if flexural strength is of primary concern, the use of smaller size coarse aggregate can help achieve better uniformity in strength.

5.4.3 *Combined aggregate grading*—Gradations requiring between 8 percent and 18 percent for large top size aggregates (such as $1^{1}/_{2}$ in.) or 8 percent and 22 percent for smaller top size aggregates (such as 1 in. or $^{3}/_{4}$ in.) retained on each sieve below the top size and above the No. 100 sieve have proven to be satisfactory in reducing water demand while providing good workability. The ideal range for No. 30 and No. 50 sieves is 8 percent to 15 percent retained on each. Often, a third aggregate is required to achieve this gradation.[23] Typically, 0 percent to 4 percent retained on the top size sieve and 1.5 percent to 5.0 percent on the No. 100 sieve will be a well graded mix. This particle size distribution is appropriate for round or cubically-shaped particles in the No. 4 through the No. 16 sieve sizes. If the available aggregates for these sizes are slivered, sharp, or elongated, 4 percent to 8 percent retained on any single sieve is a reasonable compromise. Mixture proportions should be adjusted whenever individual aggregate grading varies during the course of the work.

5.4.4 *Aggregate quality*—Compliance with ASTM C 33 and C 330 generally ensures aggregate of adequate quality, except where one of the following conditions will be severe: chemical attack, or abrasion in Class 7 and 8 floors. See ACI 201.2R for a more complete discussion of precautions under these conditions. Sections 5.4.6 and 5.4.8 discuss special abrasion-resistant and nonslip aggregates respectively. The guidelines of ACI 201.R and ASTM C 33 and its appendix should be followed where there is concern about the possibility of alkali-aggregate reaction.

5.4.5 *Special-purpose aggregates*—Decorative and non-decorative mineral aggregate and metallic hardeners are used to improve the properties of the slab surface. These materials applied as dry shakes on top of the concrete are floated

and troweled into the floor surface to improve the abrasion resistance, impact resistance, achieve nonslip surfaces, or to obtain a decorative finish. In this document, the term "dry-shake" is applied to premixed materials, which may be mineral aggregate, metallic, or colored. The term "embedded" is a more generic term used where the material can be furnished in either premixed or bulk form. Trap rock and emery are two examples of materials that can be furnished in bulk form.

5.4.6 *Wear-resistant aggregates*—Hard, abrasion-resistant aggregates, such as quartz, emery, and traprock, as well as malleable metallic hardeners, are frequently used as surface treatments.[3] They are applied as dry shakes and finished into the surface of the floor to improve its abrasion and wear resistance.

Nonmetallic surface hardeners should be used on floors subjected to heavy frequent forklift or hard-wheeled traffic (Table 2.1). Metallic hardeners in sufficient quantity should be considered for use when heavy steel wheel or intense point impact loading is anticipated. Chloride-bearing admixtures should not be used in conjunction with a metallic floor hardener.

Mineral aggregate and metallic surface hardeners are factory premixed with specially selected portland cement and plasticizers. Some mineral aggregates can be supplied in bulk and mixed with cement onsite. These aggregates, in properly graded sizes, can also be used in topping mixes.

5.4.7 *Surface treatment for electrically conductive floors*—Concrete floors can be made electrically conductive by using specially prepared metallic hardeners (dry shakes). Electrically conductive floors are also required to be spark-resistant under abrasion or impact. For protection against abrasion sparks, care should be taken in the choice of aggregates. Since construction techniques for these floors are rather specialized, specific recommendations of the product manufacturer and engineer should be followed.[24]

The electrical resistance of such floors can be determined by reference to the appropriate specification of the Naval Facilities Engineering Command.[25] A typical test for spark resistance under abrasion or impact is given in the above specification, as well as the National Fire Protection Association, NFPA 99 specification. A factory premixed metallic surface hardener containing a conductive binder is commonly used for these floors. This hardener is floated and troweled into the surface of freshly placed concrete (Section 8.6).

Special conductive curing compounds should be used to cure these floors. Conductive floors should not be used in areas expected to be continuously moist.

5.4.8 *Slip-resistant aggregates*—Slip-resistant aggregates should be hard and nonpolishing. Fine aggregates are usually emery or a manufactured abrasive. The slip resistance of some aggregates can be improved by replacing the fines with those of a more slip-resistant aggregate. To improve slip resistance, extremely soft aggregates like vermiculite can be troweled into the surface of freshly placed concrete, and then removed later by scrubbing after the concrete has hardened.

5.4.9 *Decorative aggregates*—Decorative aggregates can be of many minerals and colors. They should be sound, clean, nonreactive, and of good quality. The most common are quartz, marble, granite, and some ceramics. Rocks, shells, brass turnings or other brass pieces, and ball bearings have also been used. Shapes resembling spheres and cubes are preferable to flat or highly irregularly-shaped pieces, which can become dislodged easily. It is usually preferable to have aggregate of only one sieve size.

5.5—Water

Mixing water should be potable. Nonpotable water can be used if 7- and 28-day strengths of 2-in. (50-mm) mortar cubes made with it are equal to at least 90 percent of the strengths of cubes made from similar mixtures using distilled water and tested in accordance with ASTM C 109. ACI 301 discusses mixing water, as do Steinour[26] and others.[27] Also see AASHTO T 26.

5.6—Admixtures

Admixtures should be used when they will effect a specific desired change in the properties of the freshly mixed or hardened concrete. They should be used in accordance with the instruction and principles given in ACI 212.1R and 212.2R and the guidelines for chloride limits given in Section 5.6.3. If more than one type of admixture is used in the same concrete, each should be batched separately. A second admixture can significantly affect the required dosage of both admixtures; therefore, preliminary tests are recommended to assure compatibility. Sample slabs made under the anticipated job conditions of temperature and humidity can also be used to help evaluate admixture performance, and to allow necessary adjustments affecting workability, finishability, and setting time prior to the start of the slab installation. Some admixtures are not compatible with shrinkage-compensating concrete because they adversely affect expansion, bond to steel, and shrinkage (ACI 223).

5.6.1 *Air-entraining admixtures*—Concrete for use in areas that will be exposed to freezing temperatures while moist should contain entrained air (Section 6.2.7). Entrained air is not recommended for concrete to be given a smooth, dense, hard troweled finish since blistering and delamination may occur. Smaller percentages of entrained air may reduce bleeding and segregation, and may be used for floors and slabs using other finishes when they improve finishability of concretes not exposed to freezing. Air-entraining admixtures, when used in the concrete as recommended in Chapter 6, should meet the requirements of ASTM C 260. Consistent control of air entrainment is necessary.

In most cases, concrete for trowel-finished interior concrete floors made with normal weight aggregates should not include an air-entraining admixture; the maximum air content for these concretes should normally be 3 percent. Higher air contents make the surface difficult to finish, and can lead to surface blistering and peeling during finishing.

5.6.2 *Chemical admixtures*—Chemical admixtures should meet the requirements of ASTM C 494 for whichever of the following types are to be used:

• Type A water-reducing
• Type B retarding

•Type C accelerating

•Type D water-reducing and retarding

•Type E water-reducing and accelerating

•Type F high-range water-reducing (superplasticizer)

•Type G high-range water-reducing (superplasticizer) and retarding.

The superplasticizers should also meet the requirements of ASTM C 1017. Water-reducing and combination admixtures should provide the additional advantage of increased compressive and flexural strength at ages less than 6 months. The retarding admixtures can be useful in delaying initial set and extending time available for final finishing in hot weather; however, excessive retardation can cause surface crusting or plastic shrinkage cracking. Accelerating admixtures increase the rate of strength gain at early ages and can be useful in cold weather.

High-range water-reducing admixtures (superplasticizers) can be used to greatly reduce the water content in concrete while maintaining a given consistency. The resultant shrinkage reduction, if any, may not parallel the water reduction. They also can be used to increase slump significantly without the need to increase the water content of the original mixtures. High slumps, however, can cause consolidation and finishing problems; if high slumps are used, consolidation and finishing methods should be modified to avoid segregation of the concrete and finishing before the concrete is sufficiently stiff.

Admixtures conforming to ASTM C494 will not necessarily reduce shrinkage nor improve the finishing characteristics of the concrete.[28] Shrinkage tests as indicated in Section 5.2 can be performed.

The Committee recommends that a representative test slab be cast at the jobsite so that the workability, finishability, and setting time of the proposed mixture can be evaluated by the project team (ACI 212.3R and ACI 212.4R).

5.6.3 *Chlorides*—Studies have shown that chlorides are significant contributors to corrosion of steel in concrete. The problem is particularly severe when dissimilar metals are embedded in concrete, or when reinforced concrete is placed over galvanized decking. Corrosion products can cause expansion, cracking, and spalling.

Limits on chloride in fresh concrete mixtures are based on the recommendations of ACI 222R. The following concrete should not include any intentionally added calcium chloride:

Prestressed concrete; floors over prestressed concrete or galvanized deck; floors containing two kinds of embedded metals; conventionally reinforced concrete in a moist environment and exposed to deicing salts or saltwater mist; parking garage floors in northern climates; structures near bodies of saltwater; floors or slabs containing snow-melting electrical radiant heating systems; and floors finished with metallic dry shakes.

Noncorrosive, nonchloride accelerators are available for use in cold weather. The admixture manufacturer should be able to provide long-term data (of at least a year's duration) demonstrating noncorrosivity using an acceptable accelerated corrosion test method such as one using electrical poten-

tial measurements. Data from an independent laboratory are preferable.

If accelerated set or high early strength is desired, either a noncorrosive nonchloride accelerator or high-early strength (Type III) cement can be used; alternatively, 100 to 150 lb per cu yd (59 to 89 kg/m^3) of additional Type I or Type II cement can be used in the mixture. A significant decrease in setting time may not be realized with the increased cement content. The increased cement and water demand can increase shrinkage and curling.

Heated concrete may be required for cold weather construction (ACI 306R). The use of additional Type I or Type II cement is recommended in lieu of using chloride-based accelerators.

When used, calcium chloride should be added as a water solution in amounts of not more than 1 percent to 2 percent by weight of cement. It will accelerate the rate of strength development and decrease setting time. Calcium chloride, in dosages as high as 1 percent to 2 percent, does not significantly lower the temperature at which the concrete will freeze. It accelerates the rate of strength development and thereby decreases the length of time during which protection against freezing must be provided. Setting time is decreased, thereby reducing finishing time.

Calcium chloride tends to darken the color of concrete and can cause variations in color of the hardened concrete. The difference in color is most noticeable when slabs with calcium chloride are adjacent to those without (Fig. 11.9). If concrete containing calcium chloride is not adequately cured, the surface can show light and dark spots. Calcium chloride should not be dispensed dry from bags. Dry-flake material frequently absorbs moisture and becomes lumpy. Pellet-type calcium chloride must be completely dissolved prior to addition to concrete or pop-outs will result from any undissolved pellets.

5.6.4 *Expansive cementitious admixtures*—Specifically formulated dry-powder admixtures can be blended with portland cement at the batch plant to produce shrinkage-compensating concrete. Concrete incorporating the same materials that will be used for the anticipated project should be tested for expansion by ASTM C 878 (see ACI 223 for full details). It is also recommended that the compatibility of the expansive cementitious admixture and portland cement be checked by the use of ASTM C 806.

5.6.5 *Pozzolans*—A number of natural materials, such as diatomaceous earth, opaline cherts, clays, shales, volcanic tuffs, and pumicites are used as pozzolans. Pozzolans also include fly ash and silica fume.[29] Information on the use of slag can be found in ACI 226.1R and on fly ash in ACI 226.3R. For information on silica fume, see Reference 29. When these materials are used in concrete, except silica fume, the time of set is frequently extended and the color of concrete can be different from that produced when portland cement is the only cementitious component.

ASTM C 618 fly ash, Class F or Class C, is frequently incorporated in concrete. Fly ash can affect the setting time, and it is often helpful in hot weather by delaying set time, or as an aid in pumping concrete (Refer to ACI 226.3R). In

floors and slabs, fly ash is often substituted for portland cement in quantities up to about 20 percent fly ash by mass of cementitious materials.

In cool weather, fly ash will usually delay the setting and finishing of the concrete unless measures—increasing the concrete temperature or using an accelerator—are taken to compensate for the low temperatures.

Silica fume is used as a portland cement replacement or cementitious addition in an amount typically between 5 percent and 10 percent by mass of the total cementitious material. The use of silica fume can increase both the impermeability and the strength of the concrete. Special attention should be given to avoiding plastic shrinkage cracking during placing and finishing, by using evaporation-retardant chemicals sprayed onto the plastic concrete surface or by using fog sprays in the air above the concrete. Early and thorough curing of the slab is also very important to minimize cracking.

5.6.6 *Coloring admixtures*—Pigments for colored floors should be either natural or synthetic mineral oxides or colloidal carbon. Synthetic mineral oxides can offer more intensity in color, but they are normally more expensive. Pigments can be purchased alone or interground with a water-reducing admixture for mixing into the batched concrete to produce integrally-colored concrete. Colored aggregate-type surface hardeners containing pigments can also be used. These pigmented mineral aggregates or metallic hardeners contain mineral oxide pigment, portland cement, a well-graded mineral aggregate or metallic hardener, and plasticizers. Pigments for integrally-colored concrete should conform to ASTM C 979 and have uniform color. It should be recognized that carbon-black pigments especially manufactured for this purpose will appear lighter in color at an early age. The prepared mixtures should not contain pigments that are not mineral oxides. Job-proportioning or job-mixing of material for monolithic colored surfaces is not recommended. The use of these materials is described in Section 8.6. Coloring admixtures should be lime-proof and contain no calcium chloride. Curing compounds for these slabs should be the same as those used on the approved sample panels (Chapter 8).

5.7—Liquid surface treatments
Some floor slabs, improperly constructed, can have relatively pervious and soft surfaces that wear or dust rapidly. Though the life of such surfaces can be short, it can be extended by using surface treatments containing certain chemicals, including sodium silicate and the fluosilicates of magnesium and zinc. When these compounds penetrate the floor surface, they react chemically with calcium hydroxide (a product of cement hydration) to form a hard, glassy substance within the pores of the concrete, thereby reducing dusting of the floor and creating a denser, harder surface.

Liquid surface treatments should be considered only as emergency measures for treatment of deficiencies.[30] They are not intended to provide additional wear resistance in new, well-designed, well-constructed and cured floors, nor to permit the use of lower quality concrete. The most effective use of liquid surface treatments is on existing floors.

New floors should be of sufficiently good quality that such treatments are not required.

If for any reason these surface treatments are to be applied to new concrete floors, the floor should be moist cured. Liquid membrane-forming curing compounds should not be used because they prevent penetration of the liquid treatment. These surface treatments should be applied only to concrete floors that are at least 28 days old, and that have been thoroughly moist cured and allowed to air dry.

5.8—Reinforcement
5.8.1 *Reinforcing steel, mats, or welded wire reinforcement*—Deformed bars, bar mats, or welded wire reinforcement usually are required in suspended structural floors as part of the structural design. They can also be called for in the specifications for slabs on ground as discussed in Section 3.2.4. Deformed bars should conform to the requirements of ASTM A 615, A 616, or A 617. Bar mats conforming to ASTM A 184 can also be used. Welded wire reinforcing should conform to ASTM A 185 or A 497.

5.8.2 *Post-tensioning*—Post-tensioning can be used in slabs on ground and suspended slabs to address specific design requirements. Prestressing steel for use in floors and slabs should conform to the requirements of ASTM A 416. The post-tensioning tendons can be bonded or unbonded. Unbonded tendons should meet or exceed specifications published by the Post-Tensioning Institute.[16]

5.8.3 *Synthetic fibers*—Synthetic fibers for use in concrete floors increase the cohesiveness of concrete and should meet the requirements outlined in ASTM C 1116. The most widely used synthetic fibers are polypropylene and nylon, although other types are available. Polypropylene fibers are available in both fibrillated and monofilament form; nylon fibers are only available in monofilament form.

Synthetic fibers are added to the concrete mixer in quantities generally less than 0.2 percent by volume of the concrete. They are generally used in floors and slabs in quantities of from 0.75 to 1.5 lb per cu yd (0.44 to 0.89 kg/m^3). Synthetic fibers are used in floors to minimize plastic shrinkage cracking of concrete. These fibers should not be used to replace temperature and shrinkage reinforcement because they have little impact on the behavior of concrete after it hardens.

5.8.4 *Steel fibers*—Steel fibers for use in floors and slabs should conform to the requirements of ASTM A 820. Steel fibers made from wire, slit sheet, milled steel, and melt extract are available and are normally deformed or hooked to improve bond to the hardened matrix. Steel fibers are added to the concrete mixer in quantities ranging from 0.0625 percent to 1 percent by volume of the concrete (8 to 132 lb per cu yd; 4.7 to 78 kg/m^3). Quantities of from 0.25 percent to 0.50 percent by volume of the concrete (34 to 68 lb per cu yd; 20 to 40 kg/m^3) are typical.

Steel fibers are used in floors to minimize visible cracking, increase shear strength, increase the flexural fatigue endurance and impact resistance, and increase flexural toughness. The increases in mechanical properties achieved depend primarily on the type and amount of fiber used, and can result

Table 6.2.1— Recommended strength and maximum slump at point of placement for each class of concrete floor

Floor class*	28-day compressive strength		Maximum slump	
	psi	MPa	in.	mm
1, 2, and 3	3000	21	5	125
4 and 5	4000	28	5	125
6	4500	31	5	125
7 base	3500	24	5	125
7 bonded topping†	5000-8000	35-55	3	75
8 unbonded topping†§	4000-8000	28-55	3	75
9 superflat†	4000 or higher	278 or higher	5	125

*Refer to Table 2.1 for floor class definitions.

†The strength required will depend on the severity of usage.

§Maximum aggregate size not greater than one-quarter the thickness of unbonded topping.

Table 6.2.4— Minimum cementitious materials requirements for floors*

Nominal maximum size aggregate		Cementitious material content	
in.	mm	lb/yd^3	kg/m^3
$1\frac{1}{2}$	38	470	279
1	25	520	308
$\frac{3}{4}$	19	540	320
$\frac{1}{2}$	13	590	350
$\frac{3}{8}$	10	610	362

*See Section 5.6.5 for minimum portland cement requirements.

in reduced floor thickness and increased contraction joint spacing.[31]

5.8.5 *Fiber characteristics—*Crack reduction, material properties, and mixture proportions are thoroughly discussed by Balaguru.[32] Additional information is available in ACI 544.1R, 544.2R, 544.3R, and 544.4R.

5.8.6 *Dowels and load transfer devices—*Dowels required for load transfer can be round or square. Square dowels are available with expansion material on the vertical sides to allow for some horizontal movement. Round dowels for slab-on-ground installation should meet ASTM A36 or ASTM A615, Grade 40 minimum. Square dowels should meet ASTM A36. The diameter or cross sectional area, length, and specific location of dowels as well as the method of support should be specified by the architect/engineer. See Section 3.2.7 for more information on load transfer mechanisms for slabs on ground.

5.9—Curing materials

ACI 308 lists many coverings and membrane-forming liquids that are acceptable for curing concrete floors. Since curing is so vital to good flatwork, the characteristics of curing materials suitable for flatwork are set forth here in great detail. Also see Chapter 9 for the purpose, methods, and length of curing.

5.9.1 *Wet burlap—*If kept continually moist, burlap is an effective material for curing concrete surfaces. Old burlap from which the sizing has disappeared (or has been removed) is easier to wet than new burlap.

Care should be taken that the burlap used does not stain the concrete or come from sacks that once contained sugar; sugar retards the hardening of concrete and its presence could result in a soft surface. The requirements for burlap are described in AASHTO M182. White, polyethylene-coated burlap is available; the polyethylene is helpful in keeping the burlap moist longer, but it makes rewetting more difficult. Refer to ASTM C171.

5.9.2 *Plastic film, waterproof paper, or combination polyethylene/burlap sheets—*Plastic film, waterproof paper or polyethylene/burlap sheets for curing should allow a moisture loss of no more than 0.055 g/cm^3 in 72 hrs when tested according to ASTM C 156. Polyethylene plastic film with the same thickness and permeance used for vapor retarders below slabs on ground (Section 3.2.3) should be satisfactory. Waterproof paper should meet the requirements of ASTM C 171.

5.9.3 *Spray-applied membranes—*Liquid membrane-forming curing compounds should meet the provisions of ASTM C 309, which describes the requirements for both clear and pigmented types. White or gray compounds are used for their good light-reflectance. Colored curing compounds are available for colored concrete. Dissipating resin-based materials can be used on slabs receiving applied finishes or subsequent liquid surface treatments. ASTM C 309 allows moisture loss of 0.55 kg/m^2 in 72 hours at a curing compound coverage of 200 sq ft per gal (4.91 m^2/L) when applied in compliance with ASTM C 156. Special conductive curing compounds should be used to cure electrically conductive and spark-resistant floors. It is always important

to determine if a dissipating or nondissipating product should be used. The use of a nondissipating compound can be incompatible with the installation or application of future floor coverings.

For floors designed for high wear resistance, optimum top surface strength development, and minimal cracking, it is desirable to use curing compounds that offer high water retention. When a mineral aggregate or metallic surface hardener is used, the curing procedure and specific product used for curing should be approved by the manufacturer of the hardener. A high-solids-type curing compound can limit maximum moisture loss to 0.030 g/cm^2 at a coverage of 300 sq ft per gal (7.36 m^2/L)—less than 50 percent of that allowed by ASTM C 309 (ACI 308).

Compounds should also be tested in accordance with ASTM C1151; results less than or equal to 3.7 x 10^{-6} cm^2/s for the difference between the top and bottom *Ka* (absorptivity) values represent an acceptably cured sample. More stringent criteria can be appropriate for some projects. Manufacturer's written instructions should be followed for both the number of coats and the coverage rate needed to meet the appropriate ASTM or project requirements. Periodic field testing to evaluate actual performance is recommended. One practical test for concrete surfaces to receive a moisture-sensitive covering is to apply a 5x5-ft (1.5x1.5-m) black polyethylene sheet, sealed to the slab with tape at the edges. No significant amount of moisture should be present when the sheet is removed after 24 hours. Tests should be conducted at intervals of approximately 15,000 sq ft (1400 m^2).

It is always important to determine if a dissipating or nondissipating product should be used. When a mineral aggregate or metallic surface hardener is used, it is important that the curing method be compatible with recommendations of the hardener manufacturer.

5.10—Evaporation reducers

Evaporation reducing chemicals can be sprayed on the plastic concrete one or more times during the finishing operation to minimize plastic shrinkage cracking when the evaporation rate is high. These products should be used in strict accordance with the manufacturer's directions; they should never be used during the final troweling operations because they discolor the concrete surface.

5.11—Gloss-imparting waxes

Concrete waxes to impart gloss to concrete surfaces are available from various manufacturers. Some also are curing compounds; for such use, they should meet or exceed the water-retention requirements of ASTM C 309.

5.12—Joint materials

Certain two-component semirigid epoxy resins, polysulfides, and urethanes can be used to fill joints where the joint edges need support to withstand the action of small, hardwheeled traffic. These are the only materials known to the Committee that can provide sufficient shoulder support to the edges of the concrete and prevent joint breakdown. Two-component epoxy resins are desirable because their curing is inde-

pendent of job site conditions. Such joint materials should be 100 percent solids and have a minimum Shore A hardness of 80 when measured in accordance with ASTM D 2240. See Section 9.10 for more details on joint filling and sealing.

Preformed elastomeric sealants are useful for some applications. They should not be used where subjected to the traffic of small, hard wheels. They can be quickly installed, they require no curing, and if properly chosen, they can maintain a tight seal in joints that are subject to opening and closing. See ACI 504R for more information on preformed elastomeric sealants.

Preformed asphalt impregnated or plain fiber materials or compressible foam are used in expansion and isolation joints, depending on the anticipated movement. These materials and their appropriate use are described in detail in ACI 504R.

5.13—Volatile organic compounds (VOC)

Many users and some states require materials to meet VOC limits. Liquid materials are of greatest concern since they are often solvent-based. Certification of compliance with the applicable VOC limits should be required before the products are used.

Many curing compounds that comply with limits on VOC are water-based. They should not be permitted to freeze. In many cases, they cannot be reconstituted after freezing.

CHAPTER 6—CONCRETE PROPERTIES AND CONSISTENCY

6.1—Concrete properties

A concrete mixture should incorporate the most economical combination of available materials that will consistently produce concrete with the required workability, abrasion resistance, durability, strength, and shrinkage characteristics (ACI 211.1 and 211.2).

In most flatwork, the placeability of the concrete and finishability of the surface are at least as important as the abrasion resistance, durability, and strength. The former qualities will have a significant effect on the quality of the top $^1/_{16}$ or $^1/_8$ in. (1.5 or 3 mm) of the concrete surface. If the slab is floated while there is still free water on the surface, the finished surface will be of poorer quality than if it were properly floated (Section 8.3.3). Unfortunately, placeability and finishability are not easily measured. There is a tendency for specifiers to emphasize more easily determined properties such as slump and compressive strength.

Other parameters being equal, a given concrete's strength and shrinkage properties will improve as its water content is reduced. Therefore, the use of the minimum amount of water necessary to produce the required slump and workability is highly important. However, the particular cementitious materials, aggregates, and admixtures used can significantly affect the strength, setting characteristics, workability, and shrinkage of the concrete at a given water-cementitious material ratio.[33,34] Furthermore, the amount of water required to produce a given slump depends on the maximum size of coarse aggregate, aggregate gradation, particle shape and surface texture of both fine and coarse aggregates, air con-

tent, and the admixtures used, as well as the temperature and humidity at the time of placement. Using larger maximum-size aggregate or improving the over-all aggregate gradation reduces the mixing-water requirement.

Air-entraining admixtures produce a system of small air bubbles that reduce the mixing water requirement. Concretes containing entrained air are generally proportioned to have the same amount of coarse aggregate as similar non-air-entrained concretes. They are made with less mixing water and less fine aggregate; however, in richer mixes this may not offset the strength reduction that can result from intentional entrainment of air. It is preferable not to use air-entraining admixtures in floors that are to have a dense, smooth, hard-trowelled surface.

The optimum quality and content of fine aggregate in concrete for floors should be related to the slump of the concrete and the abrasive exposure to which the floor will be subjected. Concretes should be sufficiently plastic and cohesive to avoid segregation and bleeding.[34] Less fine aggregate should be used in concrete with low slump—less than 1 in. (25 mm)—since this concrete does not normally bleed or segregate. Decreased fine aggregate contents can improve resistance to abrasion if the concrete exhibits little bleeding and segregation.

Laboratory trial batches should be used to establish optimum proportions of ingredients. If concrete mixtures have been used successfully under similar conditions in other jobs, the laboratory trial batches can be omitted. Records of gradations of fine and coarse aggregates from concrete mixtures should be retained.

Trial batch proportions should generally be in accordance with ACI 211.1 or 211.2. However, adjustments of fine aggregate content may be necessary to obtain the best workability.[35]

6.2—Recommended concrete mixture

6.2.1 *Required compressive strength and slump*—Two approaches for selecting mixture proportions are discussed in Section 6.2.4. Regardless of the approach, the design strengths shown in Table 6.2.1 should be used for the various classes of concrete floors.

The architect/engineer should be consulted as to the strength to be achieved by concrete prior to subjecting the slab to early construction loads. To obtain this strength quickly, it may be necessary to use more cementitious materials than the minimum amount shown in Table 6.2.4, or to proportion the concrete for a 28-day strength higher than that shown in Table 6.2.1. Compressive strengths should be used for jobsite control.

The slump indicated for each floor class shown in Table 6.2.1 is the recommended maximum at the point of placement to prevent segregation, and yet provide adequate workability of the concrete. A one-time jobsite slump adjustment should be permitted as outlined in the "Tempering and control of mixing water" provisions of ACI 301, or the "Mixing and delivery" provisions of ASTM C 94 (Section 7.3.2).

6.2.2 *Required finishability*—Concrete for floors should have other desirable characteristics in addition to strength.

There should be sufficient paste to allow the finisher to completely "close" the surface and to achieve the required surface tolerances, hardness, and durability.[35]

6.2.3 *Required durability*—The procedures for producing durable concrete outlined in ACI 201.2R apply to floors and slabs. Concrete floors exposed to freezing and thawing while moist should have a water-cementitious material ratio not greater than the values given in the following paragraph. These w/cm ratio requirements can be lower than those required for strength alone. Additionally, these concretes should have adequate entrained air.

Requirements based only on durability may yield concrete compressive strengths much higher than normally required for structural concerns. Concrete floors and slabs subjected to moderate and severe exposures to freezing and thawing, as defined in ACI 201.2R, should have a w/cm ratio no greater than 0.50. Concrete subjected to deicing chemicals should have a w/cm ratio no greater than 0.45. Reinforced concrete exposed to brackish water, seawater, deicing chemicals, or other aggressive materials should have a w/cm ratio no greater than 0.40. The Committee recognizes that there is no direct correlation between compressive strengths and w/cm ratios and suggests that the two not be combined in a specification. When durability is a concern, w/cm ratios should be specified. For informational purposes, various w/cm ratios are likely to produce the following relative compressive strengths or higher: .50 [4000 psi (28 MPa)]; 0.45 [4500 psi (31 MPa)]; 0.40 [5000 psi (34 MPa)].

Entrained air is necessary in concrete subjected to freezing and thawing when moist, or subjected to deicing chemicals. Recommended air contents for hardened concrete for various exposure conditions, aggregate types, and maximum size aggregates are given in ACI 201.2R. Properly air-entrained concrete should achieve a compressive strength of 4000 psi (28 MPa) prior to being subjected to freezing and thawing in a moist condition. Prior to the application of any deicing chemicals, floors should receive some drying and should reach a strength level of 4000 psi (28 MPa).

Air contents within the limits recommended will cause significant strength reductions in rich concretes, but the effect will be less important in lean concretes. Air contents in excess of the recommended quantities will reduce strength in rich mixtures approximately 3 percent to 5 percent per 1 percent increase in air content, and will reduce abrasion resistance correspondingly.

6.2.4 *Concrete mixture*—In addition to meeting structural requirements, concrete for floors should provide adequate workability necessary to obtain the required finish and floor surface profile. Floors that are required to be impermeable, resistant to freezing and thawing and deicing chemicals, or to meet the requirements of ACI 211.2, 223, or 318, should conform to more stringent criteria. In general, w/cm ratios in the range of 0.47 to 0.53 are applicable for most interior floors of Class 4 and higher.

Total water content can have a major impact on the bleeding characteristics of the concrete, as well as the potential for shrinkage, so use of the lowest practical quantity of water in the concrete mixture is recommended.

The Committee recommends that the concrete mixture be accepted on the basis of (1) a minimum cementitious material content as indicated in Table 6.2.4, or (2) a demonstration to the architect/engineer that a proposed concrete mixture will be capable of producing a floor of acceptable finish and appearance while meeting the strength requirements of Table 6.2.1 and the project.

If a history of finishing properties is not available for a concrete mixture, a trial slab of concrete should be placed under job conditions to evaluate the workability, finishability, setting time, slump loss, hardness, and appearance of the concrete proposed for use. Materials, equipment, and personnel proposed for the project should be used. A test panel measuring at least 8x8 ft (2.5x2.5 m) and of the specified thickness can provide confirmation of some characteristics, but a test placement of a non-critical floor section is more likely to provide useful information about the finishability and setting time of concrete proposed for the work. It is recommended that the contractor who will actually finish the concrete be supplied with the information available on the proposed concrete mixture.

6.2.5 *Consistency and placeability*—The maximum slump recommended for each class of floor is given in Table 6.2.1. These slumps are intended to produce concrete of sufficient workability to be properly consolidated in the work without excessive bleeding or segregation during placing and finishing. Excessive bleeding and segregation can contribute greatly to poor performance in concrete floors. If the finished floor is to be uniform in appearance and grade, it is important that successive batches placed in the floor have very nearly the same slump and setting characteristics. See Sections 6.1, 6.2.1 and 7.3.2 regarding jobsite slump adjustment. Workability of a concrete mixture is not directly proportional to the slump. Properly proportioned concrete with slumps less than shown in Table 6.2.1 can respond very well to vibration and other consolidation procedures. Increased slump alone does not assure satisfactory workability characteristics; a discussion of the practical aspects of slump is given in Reference 35.

Slump limits in Table 6.2.1 are for concrete made with both normal weight and structural lightweight aggregate and assume the use of a normal water reducer, if required. Slumps in excess of those shown in the table may be acceptable when mid-range or high-range water reducers are used. If structural lightweight-aggregate concrete is placed at slumps higher than shown in Table 6.2.1, the coarse lightweight-aggregate particles can rise to the surface and the concrete can bleed excessively, particularly if the concrete does not contain an adequate amount of entrained air.

6.2.6 *Maximum size of coarse aggregate*—The maximum aggregate sizes in Table 6.2.4 apply to normal weight aggregates. The largest practical size aggregate should be used if economically available, and if it will satisfy the requirements that maximum size not exceed three-quarters of the minimum clear spacing of reinforcing bars nor one-third of the depth of the section. Structural lightweight aggregates are not generally furnished in sizes larger than $^3/_4$ or 1 in. (19 or 25 mm); however, some lightweight aggregates provide maximum strength with relatively fine gradings.

6.2.7 *Air content*—Moderate amounts of entrained air for purposes other than durability as described in Section 6.2.3 can be used to improve workability, particularly with lean and harsh concrete mixtures, or with poorly graded aggregates. The Committee recommends that concretes made with structural lightweight aggregates contain some entrained air. Specific recommendations for air content should be secured from the concrete supplier, the manufacturer of the lightweight aggregate, or both, but the air content should not be lower than 4 percent.

It is recommended that an air entraining agent not be specified or used for concrete to be given a smooth, dense, hard-troweled finish since blistering or delamination may occur. These troublesome finishing problems can develop any time the total air content is in excess of 3 percent. This is particularly true when monolithic surface treatments are applied.

Some variation in the air content of air-entrained concrete is common, and this can make it difficult to time the finishing operations. Exposure conditions that dictate the need for air-entrainment should be discussed with the architect/engineer before proceeding.

CHAPTER 7—BATCHING, MIXING, AND TRANSPORTING

Detailed provisions relating to batching, mixing, and transporting concrete are available in ASTM C 94, ASTM C 1116, and ASTM C 685.

7.1—Batching

Whether the concrete is mixed onsite or in a ready-mixed concrete operation, the materials should be batched within the following limits:

Cement ±1 percent
Added water ±1 percent
Fine and coarse aggregate ±2 percent
Admixtures and pigments ±3 percent

Except for site mixing on small jobs, cement should be weighed on a scale separate from that used for weighing aggregates. If batching is by the bag, no fractional bags should be used.

Aggregate should be batched by weight. Batching by volume should not be permitted, except with volumetric batching and continuous-mixing equipment (Section 7.2.1). Batch weights should be adjusted to compensate for absorbed and surface moisture. When the mixture contains special aggregates, particular care should be exercised to prevent segregation or contamination.

Water can be batched by weight or volume. The measuring device used should have readily adjustable positive cutoff and provisions for calibration.

Accurate batching of admixtures and colored pigments is critical, since they are used in relatively small quantities. Admixtures should be accurately batched at the batch plant. Admixtures that are designed to be added to the concrete at the jobsite should be incorporated in accordance with the manufacturer's recommendations. When more than one admixture

is batched, each should be batched separately and in such a way that the concentrated admixtures do not come into contact with each other. Care should be taken to avoid the freezing of admixtures in cold weather, as this can damage some of them. It is preferable to purchase pigments or colored admixtures prepackaged in batch-sized quantities. Powdered admixtures should be batched by weight, and paste or liquid admixtures by weight or volume. The volume of admixture batched should not be controlled by timing devices. Liquid admixtures are preferred but can require agitation to prevent the settling of solids.

7.2—Mixing

7.2.1 *Ready-mixed concrete*—Mixing should be in accordance with ASTM C 94 or ASTM C 1116 and should produce the required slump and air content without exceeding the authorized or approved water-cementitious material ratio. Close attention should be given to the moisture content of the aggregate. In critical jobs, or when specifically required, truck mixers should be in compliance with requirements of the project specification. In order to assure consistent slump at the point of placement, it is recommended that a small quantity of "trim water" be held out at the batch plant. The amount of withheld water should be indicated on the ticket; the truck should then leave the plant with a full water tank.

7.2.2 *Site mixing*—Mixers that produce a volume of concrete requiring less than one bag of cement should not be used. For small quantities of concrete, packaged products meeting ASTM C 387 are more convenient, and can be more accurately proportioned.

Mixing time should be sufficient to produce uniform concrete with the required slump and air content. Site mixers less than 1 cu yd (0.76 m^3) in capacity should mix for not less than 3 minutes; ordinarily 15 seconds should be added for each additional cubic yard (0.76 m^3) of capacity or fraction thereof, unless a turbine mixer is used. A longer mixing time is required for concrete with a slump of less than 3 in. (75 mm).

Equipment for volumetric batching and continuous mixing at the jobsite is available. Concrete produced in this manner should comply with ASTM C 685.

7.2.3 *Architectural concrete*—When special architectural concretes are produced using special aggregates, white cement, special cements or pigments, mixer drums and equipment should be kept clean, and any wash water should be disposed of before a new batch is introduced. Identical ingredients and quantities of materials should be used, and not less than $^1/_3$ of the capacity of the mixing drum, a minimum of three yards in a nine yard drum, and should always be in full yard increments. See ACI 303 for additional details.

7.2.4 *Shrinkage-compensating concrete*—When expansive cement or an expansive-component type admixture specifically designed for producing shrinkage-compensating concrete is required, refer to ACI 223 for details.

7.3—Transporting

7.3.1 *Discharge time*—Concrete mixed or delivered in a truck mixer should be completely discharged while the concrete still has sufficient workability to respond properly during the placing and finishing operations. The period after arrival at the jobsite during which the concrete can be properly worked will generally vary from less than 45 minutes to more than 2 hours, depending on the weather and the concrete proportions. Prolonged mixing accelerates the rate of stiffening and can greatly complicate placing and timing of finishing operations.

7.3.2 *Jobsite slump control*—When concrete arrives at the point of delivery with a slump below that which will result in the specified slump at the point of placement and is unsuitable for placing at that slump, the slump may be adjusted to the required value by adding water up to the amount allowed in the accepted mixture proportions unless otherwise permitted by the architect/engineer. Addition of water should be in accordance with ASTM C 94. The specified water-cementitious material ratio or slump should not be exceeded. After plasticizing or high-range water-reducing admixtures are added to the concrete at the site to achieve flowable concrete, do not add water to the concrete. Water should not be added to concrete delivered in equipment not acceptable for mixing. Testing samples should be taken after any necessary adjustment. See ACI 301 for further details.

7.3.3 *Delivery to point of discharge*—Concrete for floor and slab placement can be delivered to the forms directly from a truck mixer chute, or by pump, belt conveyor, buggy, crane and bucket, or a combination of these methods. It is important that delivery of concrete be at a consistent rate appropriate to the size of the placement, and that the concrete be deposited as close as possible to its final location. Concrete should not be moved horizontally by vibration, as this contributes to segregation. See ACI 304R for recommended procedures.

CHAPTER 8—PLACING, CONSOLIDATING, AND FINISHING

Most of this chapter applies to both normal weight and lightweight-aggregate concrete. The proper procedures for finishing structural-lightweight concrete floors differ somewhat, however, from finishing normal weight concrete; they are discussed separately in Section 8.11.

Various finishing procedures should be executed sequentially and within the proper time period, neither too early nor too late in the concrete-hardening process. This time period is called the "window of finishability." It refers to the time available for operations taking place after the concrete has been placed, consolidated, and struck off. Surface finish, surface treatment, and flatness/levelness requirements dictate the type and number of finishing operations. All should take place within the proper time period. If the floor slab is placed during a time period of rapid hardening, this window becomes so narrow that it can present considerable difficulties to the floor contractor. The preconstruction meeting should include discussion of the measures necessary to assure a satisfactory "window of finishability."
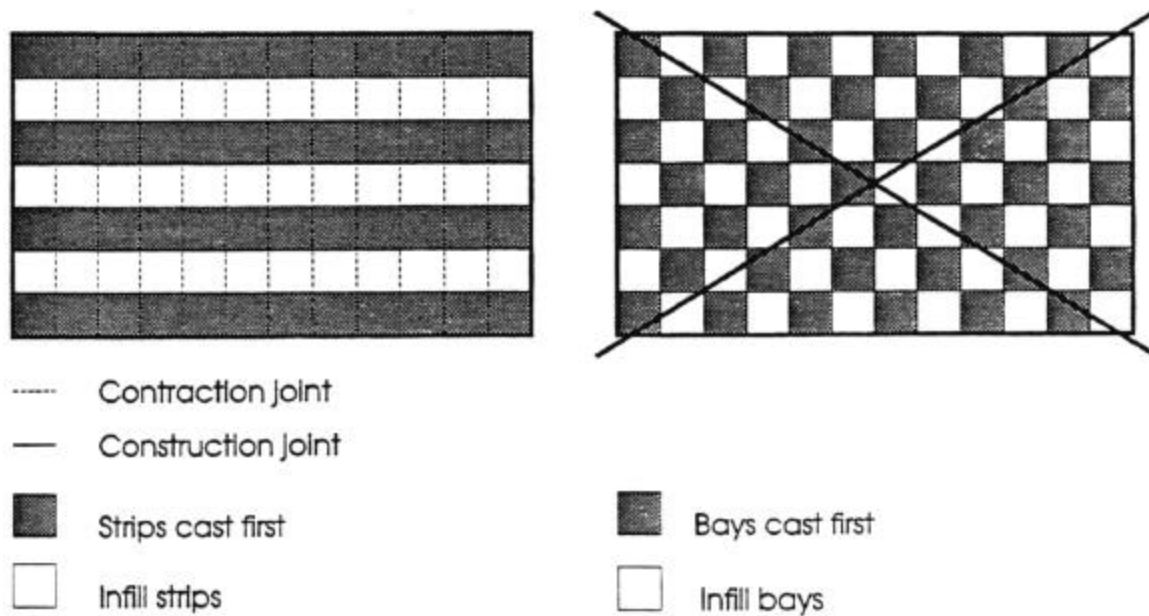
Fig. 8.1.1.1—Placing sequence: long-strip construction (left) is recommended; checkerboard construction (right) is not recommended

8.1—Placing operations

8.1.1 *Caution*—All concrete handling operations should minimize segregation, since it is difficult to remix concrete after it has been placed.

8.1.1.1 *Placing sequence*—In many cases, the most efficient way to place concrete in large areas is in long strips as illustrated in Fig. 8.1.1.1. Strip placements allow superior access to the sections being placed. Intermediate contraction joints are installed at specified intervals transverse to the length of the strips. Wide strip placements can require installation of longitudinal contraction joints.

Large block placements with interior contraction joints are an acceptable alternative to strip placements if the contraction joints are installed at specified intervals in a timely manner. The use of shrinkage-compensating concrete or some types of laser screeds are compatible with large block placements.

A checkerboard sequence of placement with side dimensions of 50 ft (15.2 m) or less as shown in Fig. 8.1.1.1 (right) has been used in the past in an effort to permit earlier placements to shrink and to obtain minimum joint width. Experience has shown that shrinkage of the earlier placements occurs too slowly for this method to be effective. Access is more difficult and expensive, and joints may not be as smooth. The Committee recommends that the checkerboard sequence of placement not be used.

8.1.1.2 *Placing sequence for shrinkage-compensating concrete*—Neither the strip method nor the checkerboard method described in Section 8.1.1.1 should be used with shrinkage-compensating concrete. Refer to ACI 223 for specific recommendations concerning placement configuration and sequence.

8.1.2 *Discharge of concrete*—The rate of discharge of concrete from a truck mixer can be controlled by varying the drum speed.

8.1.3 *Jobsite transfer*—Chutes should have rounded bottoms and be constructed of metal or be metal-lined. The chute slope should be constant and steep enough to permit concrete of the slump required to flow continuously down the chute without segregation. Long flat chutes should be avoided because they encourage the use of high-slump concrete. A baffle at the end of the chute helps to prevent segregation. The discharge end of the chute should be near the surface of previously deposited concrete. When concrete is being discharged directly onto the base, the chute should be moved at a rate sufficient to prevent accumulation of large piles of concrete. Allowing an excessively steep slope on chutes can result in high concrete velocity and segregation.

Regardless of the method of transportation and discharge, the concrete should be deposited as near as possible to its final position, and toward previously placed concrete. Advance planning should include access to and around the site, suitable runways, and the use of other devices to avoid the use of concrete with a high water-cementitious material ratio or excessive delays.

8.1.4 *Placing on base*—Mixing and placing should be carefully coordinated with finishing operations. Concrete should not be placed on the base at a faster rate than it can be spread, bull floated or darbied, and restraightened, since these latter operations should be performed before bleeding water has an opportunity to collect on the surface.

Proper sizing of finishing crews, with due regard for the effects of concrete temperature and atmospheric conditions on the rate of hardening of the concrete, will assist the contractor in obtaining good surfaces and avoiding cold joints. If construction joints become necessary, they should be produced using suitably placed bulkheads, with provisions made to provide load transfer between current and future work (Section 3.2.5.2 and 3.2.7).

8.2—Tools for spreading, consolidating, and finishing

The sequence of steps commonly used in finishing unformed concrete floor surfaces is illustrated in   . Production of high-quality work requires that proper tools be available for the placing and finishing operations. Following is a list and description of typical tools that are commonly available. Refer to Section 8.3 for suggestions and cautions concerning uses of these tools. Definitions for many of these tools can be found in ACI 116R.

8.2.1 *Tools for spreading*—Spreading is the act of extending or distributing concrete or embedding hardeners—often referred to as "shake-on" or "dry-shake"—or other special purpose aggregate over a desired area.

8.2.1.1 *Spreading concrete*—The goal of spreading operations for concrete is to avoid segregation.

8.2.1.1.1 *Hand spreading*—Short-handled, square-ended shovels, or come-alongs—hoe-like tools with blades about 4 in. (100 mm) high, 20 in. (500 mm) wide, and curved from top to bottom—should be used for the purpose of spreading concrete after it has been discharged.

8.2.1.2 *Spreading dry-shake hardeners, colored dry-shake hardeners, or other special-purpose material*—The goal of spreading operations for these materials is to provide an even distribution of product over the desired area. Generally, hand application should be used for distribution of these materials only in areas where a mechanical spreader cannot be used.

8.2.1.2.1 *Mechanical spreaders*—Mechanical spreaders are the best method of uniformly applying dry-shake hardeners, colored dry-shake hardeners, or other special purpose materials to concrete during the finishing process. These devices generally consist of (1) a bin or hopper to hold the material, (2) a vibrator or motorized auger to assist in distribution of the material, and (3) a supporting framework that allows the hopper to move smoothly over the concrete surface while distributing the material. (Fig. 8.2.1.2.1)

8.2.2 *Tools for consolidating*—Consolidation is the process of removing entrapped air from freshly placed concrete, usually by vibration. Internal vibration and surface vibration are the most common methods of consolidating concrete in supported slabs and slabs on ground. Refer to ACI 309R for

additional discussion of topics related to the consolidation of concrete.

8.2.2.1 *Internal vibration*—This method employs one or more vibrating elements that can be inserted into the fresh concrete at selected locations. Internal vibration is generally most applicable to supported cast-in-place construction.

8.2.2.2 *Surface vibration*—This process employs a portable horizontal platform on which a vibrating element is mounted. Surface vibration is commonly used in slab-on-ground, strip-type placements with edge forms. Refer to 8.2.3.2 for additional discussion.

8.2.3 *Tools for screeding*—Screeding is the act of striking off concrete lying above the desired plane or shape to a predetermined grade. Screeding can be accomplished by hand, using a straightedge consisting of a rigid, straight piece of wood or metal, or by using a mechanical screed.

8.2.3.1 *Hand screeding*—Hollow magnesium or solid wood straightedges are commonly used for hand-screeding of concrete. The length of these straightedges generally varies up to approximately 20 ft (6 m). Straightedge cross-sectional dimensions are generally 1 to 2 in. (25 to 50 mm) wide by 4 to 6 in. (100 to 150 mm) deep. Tools specifically made for screeding, such as hollow magnesium straightedges, should be used in lieu of randomly selected lumber.

8.2.3.2 *Mechanical screeding*—Various types of surface vibrators, including vibrating screeds, vibratory tampers, and vibratory roller screeds are used mainly for screeding slab-on-ground construction. They consolidate concrete from the top down while performing the screeding function. Refer to ACI 309 for a detailed discussion of equipment and parameters for proper usage.

Vibrating screeds generally consist of either hand-drawn or power-drawn single-beam, double-beam, or truss assemblies. They are best suited for horizontal or nearly horizontal surfaces. Vibrating screeds should be of the low-frequency—3000 to 6000 vibrations per min (50 to 100 Hz)—high-amplitude type, to minimize wear on the machine and provide adequate depth of consolidation without creating an objectionable layer of fines at the surface. Frequency and amplitude should be coordinated with the concrete mixture designs being used (Refer to ACI 309).

Fig. 8.2.1.2.1—Mechanical spreader

Fig. 8.2.3.2—Laser controlled screed

Fig. 8.2.4.4—Double-riding trowel with clip-on pans

Fig. 8.2.5—"Modified highway" straightedge

Laser-controlled variations of this equipment can be used to produce finished slabs on ground with improved levelness over that which might otherwise be achieved. Laser-controlled screeds can ride on supporting forms, or they can operate from a vehicle using a telescopic boom (Fig. 8.2.3.2).

Plate-tamper screeds are vibratory screeds that are adjusted to a lower frequency and amplitude. Tamper screeds work best on very stiff concrete. These screeds are generally used to embed metallic or mineral aggregate hardeners. The contractor is cautioned that improper use of this screed could embed the hardener too deeply and negate the intended benefit.

Vibratory-roller screeds knock down, strike off, and provide mild vibration. They can rotate at varying rates up to several hundred revolutions per minute, as required by the consistency of the concrete mixture. The direction of rotation of the rollers on the screed is opposite to the screed's direction of movement. These screeds are most suitable for more plastic concrete mixtures.

8.2.4 *Tools for floating*—Floating is the act of consolidating and compacting the unformed concrete surface in preparation for subsequent finishing operations. Initial floating of a concrete floor surface takes place after screeding and before bleed water comes to the surface and imparts a relatively even but still open texture to the fresh concrete surface. After evaporation of bleed water, additional floating operations prepare the surface for troweling.

8.2.4.1 *Bull floats (long-handled)*—Bull floats are used to consolidate and compact unformed surfaces of freshly placed concrete immediately after screeding operations, while imparting an open texture to the surface. They are usually composed of a large, flat, rectangular piece of wood or magnesium and a handle. The float part of the tool is usually 4 to 8 in. (100 to 200 mm) wide and 3.5 to 10 ft (1.1 to 3 m) long. The handle is usually 4 to 20 ft (1.2 to 6.1 m) long. The handle is attached to the float by means of an adjustable head that allows the angle between the two pieces to change during operation.

8.2.4.2 *Darby*—A darby is a hand-manipulated float, usually $3^1/_2$ in. (90 mm) wide and 3 to 8 ft (1 to 2.4 m) long. It

is used in early-stage-floating operations near the edge of concrete placements.

8.2.4.3 *Hand floats*—Hand tools for basic floating operations are available in wood, magnesium, and composition materials. Hand float surfaces are generally about $3^1/_2$ in. (90 mm) wide and vary from 12 to 20 in. (300 to 500 mm) in length.

8.2.4.4 *Power floats*—Also known as rotary floats, power floats are engine-driven tools used to smooth and to compact the surface of concrete floors after evaporation of the bleed water. Two common types are heavy, revolving, single-disk-compactor types that often incorporate some vibration, and troweling machines equipped with float shoes. Most troweling machines have four blades mounted to the base and a ring diameter that can vary from 36 to 46 in. (1 to 1.2 m); weight generally varies from about 150 to 250 lbs (68 to 113 kg).

Two types of blades can be used for the floating operation. Float shoes are designed to slip over trowel blades; they are generally 10 in. (250 mm) wide and 14 to 18 in. (350 to 450 mm) long. Both the leading edge and the trailing edge of float shoes are turned up slightly. Combination blades are usually 8 in. (200 mm) wide and vary in length from 14 to 18 in. (350 to 450 mm). The leading edges of combination blades are turned up slightly. The use of float shoes is recommended (Section 8.3.10).

Another attachment that is available to assist in power float operations is a pan with small brackets that slide over the trowel blades. These pans are normally used on double- or triple-platform ride-on machines and are very effective on concrete surfaces requiring an embedded hardener or coloring agent. The use of mechanical pan floating (Fig. 8.2.4.4) can also materially improve flatness of the finished floor.

8.2.5 *Tools for restraightening*—Straightedges are used to create and to maintain a flat surface during the finishing process. Straightedges vary in length from 8 to 12 ft (2.4 to 3.7 m) and are generally rectangular in cross section (though designs differ among manufacturers). When attached to a handle with an adjustable head (that is, a bull-float handle and head), these tools are frequently referred to as "modified highway" straightedges (Fig. 8.2.5).
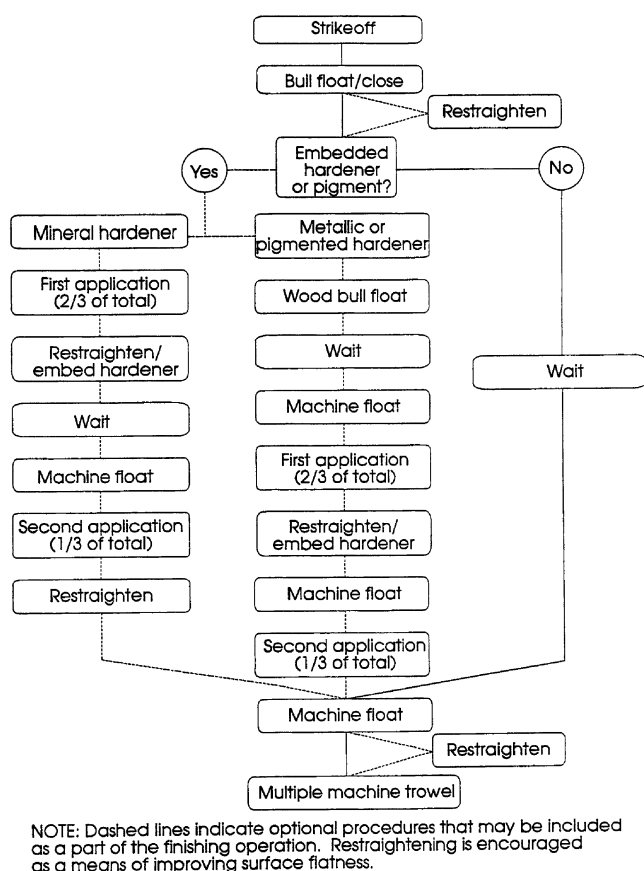
NOTE: Dashed lines indicate optional procedures that may be included as a part of the finishing operation. Restraightening is encouraged as a means of improving surface flatness.

Fig. 8.3—Typical finishing procedures (subject to numerous conditions and variables)

8.2.6 *Tools for edging*—Edgers are finishing tools used on the edges of fresh concrete to provide a rounded edge. They are usually made of stainless steel and should be thin-lipped. Edgers for floors should have a lip radius of $1/8$ in. (3 mm).

8.2.7 *Tools for troweling*—Trowels are used in the final stages of finishing operations to impart a relatively hard and dense surface to concrete floors and other unformed concrete surfaces.

8.2.7.1 *Hand trowels*—Hand trowels generally vary from 3 to 5 in. (75 to 125 mm) in width and from 10 to 20 in. (250 to 500 mm) in length. Larger sizes are used for the first troweling in order to spread the troweling force over a large area. After the surface has become harder, subsequent trowelings use smaller trowels to increase the pressure transmitted to the surface of the concrete.

8.2.7.2 *Fresno trowels*—A fresno is a long-handled trowel that is used in the same manner as a hand trowel. Fresnos are useful for troweling slabs that do not require a hard-troweled surface. These tools are generally 5 in. (125 mm) wide and vary in length from 24 to 48 in. (0.6 to 1.2 m).

8.2.7.3 *Power trowels*—Power trowels are gasoline engine-driven tools used to smooth and compact the surface of concrete floors after completion of the floating operation. Ring diameters on these machines generally vary from 36 to 46 in. (0.9 to 1.2 m); their weight generally varies from about 150 to 250 lbs (68 to 113 kg). Trowel blades are usually 6 in. (150 mm) wide and vary in length from 14 to 18 inches (350

to 450 mm). Neither the leading nor the trailing edge of trowel blades is turned up. Power trowels can be walk-behind machines with one set of three or four blades or ride-on machines with two or three sets of four blades.

8.2.8 *Tools for jointing*—These tools are used for the purpose of creating contraction joints in slabs. Contraction joints can be created by using groovers, also called jointers, or by saw-cutting.

8.2.8.1 *Groovers*—Groovers can be of the hand-held or walk-behind type. Stainless steel is the most common material. Hand-held groovers are generally from 2 to $4^3/_4$ in. (50 to 120 mm) wide and from 6 to $7^1/_2$ in. (150 to 190 mm) long. Groove depth varies from $3/_{16}$ to $1^1/_2$ in. (5 to 38 mm). Walk-behind groovers usually have a base with dimensions that vary from $3^1/_2$ to 8 in. (90 to 200 mm) in width and from 6 to 10 in. (150 to 250 mm) in length. Groove depth for these tools varies from $1/_2$ to 1 in. (13 to 25 mm).

8.2.8.2 *Saw-cutting*—The following three families of tools can be used for saw-cutting joints: conventional wet-cut (water-injection) saws; conventional dry-cut saws; and early-entry dry-cut saws. Timing of the sawing operations will vary with manufacturer and equipment. The goal of saw-cutting is to create a weakened plane as soon as the joint can be cut, preferably without creating spalling at the joint.

Both types of dry-cut tools can use either electrical or gasoline power. They provide the benefit of being generally lighter than wet-cut equipment. Early-entry dry-cut saws do not provide as deep a cut—generally $1^1/_4$ in. (32 mm) maximum—as can be achieved by conventional wet-cut and dry-cut saws.

Early-entry dry-cut saws use diamond-impregnated blades and a skid plate that helps prevent spalling. Timely changing of skid plates is necessary to effectively control spalling. It is best to change skid plates in accordance with manufacturer's recommendations.

Conventional wet-cut saws are gasoline powered and, with the proper blades, are capable of cutting joints with depths of up to 12 in. (300 mm) or more.

8.3—Spreading, consolidating, and finishing operations

This section describes the manner in which various placing and finishing operations can be completed successfully. The finishing sequence to be used after completion of the initial screeding operation depends on a number of variables related to project requirements or to the concrete finishing environment.

Project variables are generally controlled by requirements of the owner and are specified by the designer. Some examples are the choice of additives used in concrete, the requirement for an embedded hardener, and the final finish desired.

Variables subject to the environment include such items as setting time of the concrete, ambient temperature, timeliness of concrete delivery, consistency of concrete at the point of deposit, and site accessibility. Figure 8.3 is a flowchart that illustrates the normal sequence of steps in the finishing process.

8.3.1 *Spreading and compacting*—Concrete, whether from a truck mixer chute, wheelbarrow, buggy, bucket, belt

conveyor, pump, or a combination of these methods, should be delivered without segregation of the concrete components (Section 8.1). Spreading, the first operation in producing a plane surface (not necessarily a level surface, since in many cases it can be sloped for surface drainage) should be performed with a come-along or a short-handled, square-ended shovel (Section 8.2.1.1.1).

Long-handled shovels, round-ended shovels, or garden-type rakes with widely-spaced tines should not be used to spread concrete. Proper leverage, of prime importance for manipulating normal weight concrete, is lost with a long-handled shovel. Round-ended shovels do not permit proper leveling of the concrete. The tines of garden-type rakes can promote segregation and should not be used in any concrete.

Initial compacting of concrete in floors, with the exception of heavily reinforced slabs, is usually accomplished in the first operations of spreading, vibrating, screeding, darbying or bull floating, and restraightening. The use of grate tampers or mesh rollers is usually neither desirable nor necessary if cement paste splatters when they are used. If grate tampers are used on lightweight-concrete floors, only one pass over the surface with a very light impact should be permitted. Spreading by vibration should be minimized. See ACI 309R for detailed discussion.

8.3.1.1 *Structural floors*—Both suspended and on-ground structural floors can be reinforced with relatively heavy deformed reinforcing bars or with post-tensioning tendons, and typically contain other embedded items such as piping and conduit. Proper consolidation around reinforcing steel, post-tensioning anchorages, and embedded elements requires internal vibration, but care should be taken not to use the vibrator for spreading the concrete, especially in deeper sections where over-vibration can easily cause segregation.

The vibrator head should be completely immersed during vibration. Where slab thickness permits, it is proper to insert the vibrator vertically. On thinner slabs, the use of short 5 in. (125 mm) vibrators permits vertical insertion. Where the slab is too thin to allow vertical insertion, the vibrator should be inserted at an angle or horizontally. The vibrator should not be permitted to contact the base since this might contaminate the concrete with foreign materials.

8.3.2 *Screeding*—Screeding is the act of striking off the surface of the concrete to a predetermined grade, usually set by the edge forms. This should be done immediately after placement. See Section 8.2.3 for tools used for screeding.

Of all the floor-placing and finishing operations, form setting and screeding have the greatest effect on achieving the specified grade. Accuracy of the screeding operation is directly impacted by the stability of the edge forms or screed guides selected by the contractor. Consequently, care should be taken to match the forming system and the screeding method to the levelness tolerance specified.

Edge forms for slab-on-ground and suspended-slab placements are normally constructed of wood or metal. Some edge forms are constructed of concrete. The spacing between edge forms, and the support provided for them, will influence the accuracy of the screeding operation. Where edge-form spacing exceeds the width of the screed strip, intermediate screed

guides can improve the accuracy of the screeding operation. The width of these screed strips will generally vary between 10 ft (3 m) and 16 ft (5 m) and will be influenced by column spacings. Generally, screed strips should be equal in width, and should have edges that fall on column lines.

In general, slab-on-ground placements are either block placements or strip placements. Block placements generally have edge dimensions that exceed 50 feet (15 m). Strip placements are generally 50 feet (15 m) or less in width and vary in length up to several hundred feet. Suspended-slab placements are usually block placements. Where wood is used for edge forms, the use of dressed lumber is recommended. The base should be carefully fine-graded to ensure proper slab thickness.

Selection of the type of screed guide to be used for screeding operations is somewhat dependent on placement configuration. The maximum practical strip width for hand screeding is about 20 feet (6 m). Where strict elevation tolerances apply, it is wise to limit strip width for hand screeding to about 16 feet (5 m). Screeding of strip placements for slabs on ground is generally completed using some type of a vibrating screed supported by edge forms. Screeding of block placements for slabs on ground is usually accomplished using wet-screed guides, dry-screed guides, a combination of these two, or some type of laser-guided screed. For slabs on ground, an elevation change no greater than $3/8$ in. (10 mm) in 10 ft (3 m), approximately $F_L 35$, can be achieved routinely through use of laser-guided screeds. Screeding of block placements for suspended slabs is usually accomplished using either wet-screed guides, dry-screed guides, or a combination of the two.

Wet-screed guides, when used between points or grade stakes, are established immediately after placement and spreading; see Section 4.4 for setting of dry-screed guides. At the time of floor placement, before any excess moisture or bleed water is present on the surface, a narrow strip of concrete not less than 2 ft (600 mm) wide should be placed from one stake or other fixed marker to another, and straight-edged to the top of the stakes or markers; then another parallel strip of concrete should be placed between the stakes or markers on the opposite side of the placement strip. These two strips of concrete, called "wet-screed guides," are used in establishing grade for the concrete located between the guides. Immediately after wet-screed guides have been established, concrete should be placed in the area between, then spread and straightedged to conform to the surface of the wet-screed guides. It is important that the contractor confirm that proper grade has been achieved following strikeoff. High spots and low spots should be identified and immediately corrected. Low spots left behind should be filled by placing additional concrete in them with a shovel, carefully avoiding segregation. Nonconforming areas should then be rescreeded. Difficulty in maintaining the correct grade of the floor while working to wet-screed guides is an indication that the concrete mixture is too wet or that vibration is causing the guides to move.

Elevation stakes placed at regular intervals are one method of establishing grade for wet-screed guides in slab-on-

ground construction. As screeding progresses the stakes can be driven down flush with the base if expendable, or pulled out one at a time to avoid walking back into the screeded concrete. This early removal of stakes is one of the big advantages in the use of wet-screeds; in addition, grade stakes are much easier and faster to set than dry-screeds. Screeding should be completed before any excess moisture or bleed water is present on the surface.

Benefits of using wet-screed guides include economical and rapid placement of the concrete. However, successful use of wet-screed guides requires careful workmanship by craftspeople who strike off the concrete because vibration can change the elevation of the wet-screed. Wet-screed guides are difficult to employ when varying surface slopes are required and can produce inconsistent results when variations in slab thickness are required to compensate for deflection of a suspended slab. Special care is necessary to avoid poor consolidation or cold joints adjacent to wet-screed guides.

Wet-screed guides should not be used in suspended-slab construction unless the finished floor surface is level and formwork is shored at the time of strikeoff. During construction activity, vibration of reinforcing steel and the supporting platform may result in an incorrect finished grade when wet-screed guides are used. It is imperative, therefore, that grade be confirmed after strikeoff and that errors be corrected at that time by restriking the area.

Wet-screed guides should be used only for surfaces where floor levelness is not critical. For slabs on grade where floor levelness requirements are important, it is recommended that dry-screed guides be used instead of wet-screed guides. In general, surfaces produced using wet-screed guides will exhibit maximum elevation changes of at least $^5/_8$ in. (16 mm) in 10-ft (3-m). This corresponds to an $F_L 20$ floor.

Elevation variation of surfaces produced using dry-screed guides is dependent on placement-strip width and the accuracy with which the guides are installed. Generally, the maximum elevation changes that can be anticipated will be reduced as the dry-screed guides are moved closer together.

For suspended-slab construction, the desirability of utilizing dry-screed guides on both sides of each placement strip is diminished by the damage done when the contractor retrieves the guide system. For this reason, it is recommended that a combination of dry-screed guide and wet-screed guide techniques be employed on suspended slabs.

The first placement strip should always start against a bulkhead or edge of the building. Strikeoff on the interior side of the strip should be controlled through use of moveable dry-screed guides, which will provide positive control over the surface elevation along that line. The concrete edge along the moveable guide should be kept near vertical and straight. As concrete is placed and struck off, these guides are removed. When the next strip is placed, preferably in the same direction as the initial strip, the prior strip will normally have been in place for 30 or more minutes. The contractor can extend the straightedge 2 ft (600 mm) or more over the previous partially-set placement to control grade of strikeoff on that side of the strip and use moveable dry-screed guides

to control grade on the side of the strip not adjacent to previously placed concrete.

For suspended-slab construction, the procedure described in the previous paragraph has several advantages over unmodified "wet-screed" techniques or those techniques that employ dry-screed guides on both sides of each placement strip.

1. Where previously placed concrete is used as a guide for strikeoff, it provides a relatively stable guide, because it will have been in place for some time before it is used.

2. Retrieval of the dry-screed guide from areas surrounded by previously placed concrete is unnecessary, because dry-rigid guides are not used in these locations.

Moveable dry-screed guides should be used to establish grade on any suspended slabs that are not level and shored at the time of strikeoff, and for any suspended slab where increases in local slab thickness might be used to compensate for anticipated or identified differential deflection of the structure. When an increase in local slab thickness is used to compensate for differential floor deflection, it is likely that the resulting slab will be more than $^3/_8$ in. (10 mm) thicker than design thickness. The contractor should secure permission to exceed the plus tolerance for slab thickness prior to beginning construction. Refer to Section 3.3 for a discussion of suspended slab deflection and suggested construction techniques.

For construction of slabs on ground, the use of vibrating screeds—where edge forms or screed-guide rails can be used—will facilitate strike-off operations. By using a vibrating screed, crews can place concrete at a lower slump than might be practical if screeding were done by hand. Suspended slabs are seldom both level and supported at the time of construction. Vibrating screeds and roller screeds similar to those used for slab-on-ground strip placements are generally not appropriate for use in suspended-slab construction because of the probability that their use will result in slabs that are too thin in localized areas. It is essential that minimum slab thickness be maintained at all locations on suspended slabs because of fire separation requirements.

Slumps up to 5 in. (125 mm) are often recommended for concrete consolidated by vibrating screeds. If slumps in excess of 4 in. (100 mm) are used, the amplitude of vibration should be decreased in accordance with the consistency of the concrete so that the concrete does not have an accumulation of excess mortar on the finished surface after vibration.

Vibrating screeds strike off and straightedge the concrete in addition to providing consolidation. To perform significant consolidation, the leading edge of the shoe should be at an angle to the surface, and the proper surcharge (height of uncompacted concrete required to produce a finished surface at the proper elevation) should be carried in front of the leading edge.

Vibrating screeds should be moved forward as rapidly as proper consolidation allows. If not used in this manner, too much mortar will be brought to the surface in normal weight concrete; conversely, too much coarse aggregate will be brought to the surface in structural-lightweight-aggregate concrete.

8.3.3 *Floating—*The term "floating" is used to describe compaction and consolidation of the unformed concrete surface. Floating operations take place at two separate times during the concrete finishing process.

The first floating, generally called "bull floating," is by hand and takes place immediately after screeding. Initial floating should be completed before any excess moisture or bleeding water is present on the surface. *Any finishing operation performed while there is excess moisture or bleed water on the surface will cause dusting or scaling.* This basic rule of concrete finishing cannot be over-emphasized. The first floating operation is performed using a bull float, darby, or modified highway straightedge. The second floating operation takes place after evaporation of most of the bleed water and is usually performed using a power trowel with float shoes or a pan attached. The second floating operation is described in Section 8.3.10.

8.3.3.1 *Bull floating—*One of the bull float's purposes is to eliminate ridges and to fill in voids left by screeding operations. Bull floating should embed the coarse aggregate only slightly. This process prepares the surface for subsequent edging, jointing, floating, and troweling.

When the specified finished floor flatness using the F-number system restricts the difference between successive 1-ft (300-mm) slopes to a maximum of $1/4$ in. (6 mm), approximately F_F20 (Section 8.15), a traditional-width bull float of 4 to 5 ft (1.2 to 1.5 m) can be used to smooth and to consolidate the concrete surface after screeding. The use of this width bull float, however, can adversely affect floor flatness and make achievement of higher flatness extremely difficult. When the magnitude of difference between successive 1-ft (300-mm) slopes is limited to less than $1/4$ in. (6 mm)—floor flatness greater than F_F20 (Section 8.15)—an 8- to 10-ft-wide (2.4- to 3-m) bull float can be very useful in removing surface irregularities early in the finishing process. This is particularly true for suspended-slab construction, where local irregularities caused by form- or metal-deck deflection and concrete leakage can be significant.

Many contractors use an 8- to 10-ft-wide (2.4- to 3-m) bull float or modified highway straightedge after initial strikeoff to restraighten any local irregularities that can be present. Use of a traditional 4- to 5-ft-wide (1.2- to 1.5-m) bull float will provide little assistance to the finisher in correcting these irregularities. Using the wider bull float or modified highway straightedge allows the finisher to recognize and to correct irregularities at a time when significant amounts of material can be moved with relatively little effort. This simple substitution of tools can routinely produce up to a 50 percent increase in floor flatness.

In block placements for slabs on ground, and for suspended-slab placements, a wide bull float or modified highway straightedge can also be used to advantage. Applied at an angle of approximately 45 to the axis of the placement strip and extending across the joint between the current strip and the strip just previously placed, these tools can remove many irregularities that would otherwise remain if they were used only in a direction perpendicular to the axis of the placement strip.

A magnesium bull float can be used for lightweight concrete and sticky mixes, or where it is desirable to partially close the surface until it is time to float. The magnesium face of the bull float slides along the fines at the surface and thus requires less effort, and is much less likely to tear the surface.

When an embedded hardener or other special purpose aggregate is required and rapid stiffening is expected, the use of a bull float, preferably wooden, can be helpful in initially smoothing the surface after the aggregate is applied and before the modified highway straightedge is used in the initial cutting and filling operation. Inevitable variations in the uniformity of coverage when an embedded hardener or other special purpose aggregate is applied will create slight irregularities in the slab surface. Restraightening operations necessary to remove these irregularities will remove embedded material in some locations while adding to the thickness of embedded material in other locations. Experience has shown that some variation in the uniformity of embedded material coverage does not adversely impact the floor's function.

Wooden bull floats are preferable for use on normal weight concrete that receives an embedded hardener. The wood's texture moves a mortar mixture of cement and fine aggregate on the surface, permits normal bleeding, and leaves the surface open. If a magnesium bull float is used for normal weight concrete, the embedded hardener should first be forced into the concrete using a wooden float. This brings moisture to the surface and ensures proper bond of the hardener to the base slab. This is particularly important where dry shakes will be applied for color or increased wear resistance.

8.3.3.2 *Darbying—*Darbying serves the same purpose as bull floating, and the same rules apply. Since bull floating and darbying have the same effect on the surface of fresh concrete, the two operations should never be performed on the same surface. Because of its long handle, the bull float is easy to use on a large scale, but the great length of the handle detracts from the attainable leverage, so high tolerances are more difficult to achieve. A darby is advantageous on narrow slabs and in restricted spaces. Long-handled darbies should be used for better leverage and control of level. Metal darbies are usually unsatisfactory for producing surfaces meeting high-tolerance requirements. The same principles regarding the use of wooden or magnesium bull floats (Section 8.3.3.1) apply to darbies, since both darbies and bull floats are used for the same purpose following screeding.

8.3.3.3 *Hand floating—*Wooden hand floats encourage proper workmanship and timing. If used too early on any type of concrete, they stick, dig in, or can tear the surface. Used too late, they roll the coarser particles of fine aggregate out of the surface, at which time use of a magnesium float held in a flat position would be preferable. Wooden floats more easily fill in low spots with mortar; they should also be used in areas where embedded hardeners or other special purpose aggregates will be applied, floated, and finished by hand only. The use of wooden hand floats has declined largely due to the need for periodic replacement because of wear or breakage, and the greater effort and care in timing required in using them. Used at the proper time, their floating action is unequaled by other hand tools.

Magnesium hand floats require less effort. Like magnesium bull floats, they slide along largely on fines. They can be used on concrete from the time of placement to beyond the point of stiffening when a wooden float cannot be used. Magnesium floats are best used in the initial smoothing of the surface near screeds, walls, columns, or other projections, and during placing, screeding, and bull floating, when a wooden float would dig in or tear the surface. Magnesium floats can also be used on air-entrained concrete that is not to receive a troweled finish, or following wooden or power floating to produce a more uniform swirl finish not quite as roughly textured. Well-worn magnesium floats develop an edge almost as sharp as a steel trowel's, so care should be exercised to use them flat to avoid closing the surface too early or causing blisters.

Composition hand floats using resin-impregnated canvas surfaces are smoother than wooden floats and only slightly rougher than magnesium floats. They are similar to magnesium hand floats and should be used in the same manner.

8.3.4 *Highway-type straightedging*—The use of a modified highway straightedge for restraightening of the surface varies with the type of slab being installed. Experienced finishers can use this tool early in the finishing process instead of an 8- to 10-ft-wide (2.4- to 3-m) bull float. Care is needed, however, because the straightedge tends to dig into the concrete if it is used improperly. Initial restraightening with the modified highway straightedge, should immediately follow screeding. Restraightening should be completed before any excess moisture or bleed water is present on the surface. When specified differences between successive 1-ft (300-mm) slopes are $3/_{16}$ in. (5 mm) or less—flatness higher than F_F20 (Section 8.15)—a modified highway straightedge is recommended to smooth and to restraighten the surface after power floating or any floating operation that generates significant amounts of mortar. A weighted modified highway straightedge can also be used after power-trowel operations to scrape the surface, reducing local high spots. Filling of low spots is generally not appropriate after scraping with a weighted modified highway straightedge.

The flatness exhibited by any concrete floor will be determined almost exclusively by the effectiveness of corrective straightedging employed after each successive strikeoff, floating, and troweling step. Without restraightening, each step performed in a conventional concrete floor installation tends to make the surface less flat. Straightedges are capable of restraightening, or reflattening the plastic concrete, since they alone contain a reference line against which the resulting floor profile can be compared. Restraightening operations are most effective when new passes with the modified highway straightedge overlap previous passes by about 50 percent of the straightedge width. In contrast, traditional 4- to 5-ft-wide (1.2- to 1.5-m) bull floats, power floats, and power trowels are by nature wave-inducing devices. To the extent that further restraightedgings can only reduce floor-wave amplitudes and enlarge floor-wave lengths, floor surface flatness can be further improved until Class 9 floor surface quality is obtained.

The modified highway straightedge is used in a cutting and filling operation to achieve surface flatness. When using this, or any, restraightening tool, it is desirable to overlap previous work with the tool by at least 50 percent of the tool width. It is also desirable to use the tool in at least two directions, preferably in perpendicular directions to each other. For strip placements, this can be accomplished by using the straightedge at a 45 angle to the axis of the strip, and toward the end of the strip, followed by use of the straightedge at a 45 angle toward the beginning of the strip. The cutting and filling operation taking place in these two directions from the edge of a placement strip will enable the straightedge passes to cross at right angles, and to produce a flatter, smoother floor. Straightedging in a direction parallel to the strip-cast operation and to the construction joints is possible, but less desirable because this would require the finisher to stand in the plastic concrete or on a bridge spanning the strip. This "cut and fill" process can also be performed after power-floating operations (Section 8.3.10) to further improve the floor's flatness.

For slabs on ground with an embedded metallic or mineral hardener, coloring agents, or other special-purpose material, the use of a modified highway straightedge plays an important part in reestablishing surface flatness after application of the material. These products are generally applied after initial screeding or strikeoff, and even the best of applications will create minor irregularities in the surface. After the hardener or special-purpose material has been worked into the surface of the concrete using a wooden bull float, a follow-up pass using the modified highway straightedge is desirable to restraighten the surface after the embedded metallic, mineral, and special-purpose material or its coating has absorbed sufficient moisture.

Some embedded metallic dry-shake hardeners and colored dry-shake hardeners are applied immediately after the initial power float pass. When these materials are relatively fine, it is necessary to wait until this point in the finishing operation to begin their application. When applied too early in the finishing process, they tend to be forced below the surface by finishing operations. The use of a modified highway straightedge to embed these materials and to restraighten the surface after their application is a critical component of the finishing process.

The committee recommends mechanical spreaders for use in the application of metallic or mineral hardeners, colored dry-shake hardeners, or other special-purpose materials. Hand spreading sometimes results in an inadequate and uneven application of the material.

8.3.5 *Waiting*—After initial floating and restraightening have been completed, a slight stiffening of concrete is necessary before proceeding with the finishing process. Depending on job conditions, it is usually necessary to wait for this stiffening to occur. Waiting time can be reduced or eliminated by the use of dewatering techniques. No subsequent operation should be done until the concrete will sustain foot pressure with only about $1/_4$ in. (6 mm) indentation.

8.3.6 *Dewatering techniques*—For slabs on ground, the use of dewatering techniques as an alternative to waiting

should be thoroughly discussed by key parties before implementation by the contractor. Either vacuum mats, or a blotter of cement on top of damp burlap, applied to the surface of freshly placed concrete, can be used to remove significant amounts of water. While this process quickly prepares the surface for final floating and troweling, it should only be undertaken by those with successful experience in the use of these techniques. The application of dry cement directly to the surface of freshly placed concrete should be avoided; this practice promotes dusting of the floor surface and can result in reduced abrasion resistance.

Vacuum mats, or a blotter of cement on top of damp burlap, are applied after the concrete has been placed, compacted, and floated. If vacuum mats are used, vacuum is applied for about 3 to 5 min. per 1 in. (25 mm) thickness of slab.[36,37,38]

Vacuum dewatering has been used extensively in Europe. More detailed information is presented in References 36 through 38.

8.3.7 *Edging*—Edging is not required or recommended on most floors. Edgers should be used only when specifically required by the project documents. Where edging is required, utilization of walk-behind edgers is discouraged because their use can yield inconsistent results. If the floor is to be covered with tile, an edger should not be used. If required, a $1/_8$ in. (3 mm) or smaller radius edge should be used for construction joints subjected to regular vehicular traffic, although saw-cutting is the preferred method for this type of surface.

The edger is used to form a radius at the edge of the slab (Section 8.2.6). Edging or stoning will also allow construction joints to be readily visible for accurate location of sawing, when used. The second placement at a construction joint will often bond to the first placement. Sawing this joint encourages development of a clean, straight crack at the construction joint. Edging is most commonly used on sidewalks, driveways, and steps; it produces a neater looking edge that is less vulnerable to chipping. Edging should not commence until most bleed water and excess moisture have left or been removed from the surface. Instead of being edged, construction joints of most floor work can be lightly stoned after the bulkheads, or edge forms, are stripped and before the adjacent slab is placed.

8.3.8 *Hand-tooled joints*—Slabs on ground are jointed immediately following edging, or at the same time, unless the floor is to be covered with tile. If the floor is to be covered with tile, jointing is unnecessary because random cracks are preferable to tooled joints under tile. For floors to be covered with quarry tile, ceramic tile, terrazzo pavers, or cast-in-place terrazzo, the joints in slabs on ground should be aligned with joints in the rigid coverings.

The cutting edge, or bit, of the jointing tool creates grooves in the slab, called contraction joints (Section 3.2.5.3). For contraction joints, the jointing tool should have a bit deep enough to cut grooves that are one-quarter of the thickness of the slab. This forms a plane of weakness along which the slab will crack when it contracts. Jointers with worn-out or shallow bits should not be used except for form-

ing decorative, nonfunctional groves in the concrete surface. The jointer should have a $1/_8$-in. (3-mm) radius for floors. Because of limitations on bit length, hand-tooled joints aren't practical for slabs greater than 5 in. (125 mm) thick where the groove depth is $1/_4$ of the slab thickness.

It is good practice to use a straight 1x8- or 1x10-in. board (25x200- or 25x250-mm) as a guide when making the joint, or groove, in a concrete slab. If the board is not straight it should be planed true. The same care should be taken in running joints as in edging, because a hand-tooled joint can either add to or detract from the appearance of the finished slab.

8.3.9 *Preformed joints*—Preformed plastic and metal strips are also available as an alternative to the use of jointers or saw cuts for making contraction joints. If used, they are inserted in the fresh concrete at the time hand-tooled jointing would take place. Proper performance of these strips is extremely sensitive to installation. Plastic or metal inserts are not recommended in any floor surface subjected to wheeled traffic (Section 3.2.5.3).

8.3.10 *Power floating*—After edging and hand-jointing operations (if used), slab finishing operations should continue with use of either the hand float or the power float. Power floating is the normal method selected. The purposes of power floating are threefold: (1) to embed the large aggregate just beneath the surface of a mortar composed of cement and fine aggregate from the concrete; (2) to remove slight imperfections, humps, and voids; and (3) to compact the concrete and consolidate mortar at the surface in preparation for other finishing operations. In the event that multiple floating passes are required, each floating operation should be made perpendicular to the direction of the immediately previous pass.

Nonvibratory, 24- to 36-in. diameter (0.6- to 1-m) steel disk-type floats are usually employed to float low-slump or zero-slump concrete or toppings. They can also be used for additional compacting or floating following normal floating operations when the surface has stiffened to a point where it can support the weight of the machine without disturbing the flatness of the concrete.

Troweling machines equipped with float-shoe blades can be used for floating. Later float passes can use pans clipped to trowel blades. Troweling machines with combination blades could be used, but are not recommended. Floating with a troweling machine equipped with normal trowel blades should not be permitted. Contract documents should also prohibit the use of any floating or troweling machine that has a water attachment for wetting the concrete surface during finishing of a floor. Application of water by brush or machine during finishing promotes dusting of the floor surface.

Many variables—concrete temperature, air temperature, relative humidity, and wind—make it difficult to set a definite time to begin floating. The concrete is generally ready for hand floating when the water sheen has disappeared or has been removed, and the concrete will support a finisher on kneeboards without more than approximately a $1/_8$ in. (3 mm) indentation. The slab surface is ready for machine floating with the lightest machine available when

the concrete will support a finisher on foot without more than approximately a $^1/_4$ in. (6 mm) indentation, and the machine will neither dig in nor disrupt the levelness of the surface.

Normally, concrete will be ready for power floating in the same order in which it was placed. On a given placement, however, certain areas can become ready for power floating before others. The areas that should be floated first generally include surfaces adjacent to screed guides, edge forms, blockouts, walls, and columns. Areas exposed to sun tend to set more quickly than those protected by shade; surfaces exposed to wind also require attention before those protected from the wind. Generally, one or more finishers should be assigned to look after those areas that will set faster than the overall placement.

As a general rule, and under slow-setting conditions when flatness tolerances are not high, power floating should be started as late as possible; this is indicated by minimum machine indentation or when a footprint is barely perceptible. Under fast-setting conditions or when high-flatness tolerances are required, and with the understanding that abrasion resistance of the slab can be reduced, floating should be started as soon as possible; the maximum practical indentation is about ¼ in. (6 mm). When higher-flatness quality is required, the floating operation should generate sufficient mortar to assist in restraightening operations with the modified highway straightedge. Flatness/levelness tolerances can require restraightening of the surface before and after the floating operation.

The marks left by the edger and jointer should be removed by floating, unless such marks are desired for decoration, in which case the edger or jointer should be rerun after the floating operation.

Generally, when the floating operation produces sufficient mortar, restraightening after the floating operation is very beneficial. After the initial power-float pass, and while the surface mortar is still fresh, the modified highway straightedge can be used to restraighten the slab surface by removing the troughs and ridges generated by the power float. This is accomplished by cutting down the ridges and using that mortar to fill the troughs. These operations should be completed during the "window of finishability" described in the second paragraph of this chapter.

The use of the power float, as previously described, tends to create troughs under the center of the machine in the direction of travel, with ridges of mortar occurring just outside the perimeter of the blades. Around projections such as columns and sleeves, the power float tends to push mortar up against the projection. If this mortar buildup is not removed by the hand finisher, it will remain when the concrete hardens and the surface will be at a higher elevation than desired.

One method that allows proper grade to be maintained at these locations is to place a bench mark a specified distance above design grade on the projection for subsequent use by the finisher. While completing hand work around the column or sleeve, the finisher can use a template to confirm that proper grade has been maintained. Excess material can then be removed as required.

8.3.11 *Troweling*—The purpose of troweling is to produce a dense, smooth, hard surface. Troweling is done immediately following floating; no troweling should ever be done on a surface that has not been floated by power or by hand. Use of a bull float or darby without following by hand or machine floating is not sufficient.

If troweling is done by hand, it is customary for the concrete finisher to float and then steel trowel an area before moving kneeboards. If necessary, tooled joints and edges should be rerun before and after troweling to maintain uniformity and true lines.

Hand trowels that are short, narrow, or of inferior construction should not be used for first troweling. Mechanical troweling machines can be used. The mechanical trowel can be fitted with either combination blades or with those intended specifically for the troweling operation.

For the first troweling, whether by power or by hand, the trowel blade should be kept as flat against the surface as possible; in the case of power troweling, use a slow speed. If the trowel blade is tilted or pitched at too great an angle, an objectionable "washboard" or "chatter" surface will result. A trowel that has been properly "broken in" can be worked quite flat without the edges digging into the concrete. Each subsequent troweling should be made perpendicular to the previous pass. Smoothness of the surface can be improved by restraightening operations with the modified highway straightedge and by timely additional trowelings. There should be a time lapse between successive trowelings to permit concrete to become harder. As the surface stiffens, each successive troweling should be made with smaller trowel blades or with blades tipped at a progressively higher angle to enable the concrete finisher to apply sufficient pressure for proper finishing. Additional troweling increases the compaction of fines at the surface and decreases the water-cementitious material ratio of concrete near the slab surface where the trowel blades agitate surface paste and hasten the evaporation rate of water within the paste; this process results in increased surface density and improved wear resistance. Extensive steel-troweling of surfaces receiving a colored dry-shake hardener can have a negative impact on the uniformity of color. Refer to Section 8.6.2 for a detailed discussion.

The formation of blisters in the surface of the concrete during troweling can be the result of entrained air or excessive fines in the concrete mixture, of early troweling, or of an excessive angle of the trowel blades. Purposefully-added (entrained) air is not recommended on surfaces to receive a hard-troweled finish (Section 6.2.7). If the air content is acceptable, then blister formation is an immediate indication that the angle of the trowel blade is too great for the surface in that area at that particular time for the concrete and job conditions involved.

Extensive steel-troweling leaves the concrete surface with a very high sheen. Such surfaces become quite slippery when wet, and should be slightly roughened to produce a nonslip surface if they are to be exposed to the weather. A smooth-textured swirl finish can be produced by using a steel trowel

in a swirling motion (also known as a sweat finish) or by brooming the freshly troweled surface.

A fine-broomed surface is created by drawing a soft-bristled broom over a freshly troweled surface. When coarser textures are desired, a stiffer bristled broom can be used after the floating operation. A coarse-textured swirl finish can be created after completion of the power float pass and subsequent restraightening using a modified highway straightedge. A coarse-swirl pattern is normally created using a hand-held wood or magnesium float (Section 8.13.4).

During periods of hot, dry, and windy weather, troweling should be kept to the minimum necessary to obtain the desired finish. When ambient conditions create high water loss due to slab evaporation, fog spraying above the concrete or use of an evaporation retardant is necessary. After finishing, any delay in protecting the slab with curing compounds or other water-retaining materials can result in an increase in plastic-shrinkage cracking, crazing, low surface strength, dusting, and early deterioration.

8.3.12 *Saw-cut joints*—On large flat concrete surfaces, rather than hand-tooling joints, it can be more convenient to cut joints with an electric or gasoline-driven power saw fitted with an abrasive or diamond blade, and using one of the following three types of saws: conventional wet-cut; conventional dry-cut; or early-entry dry-cut.

The early-entry dry-cut process is normally used when early sawing is desired. Early-entry dry-cut joints are formed using diamond-impregnated blades. The saw cuts resulting from this process are not as deep as those produced using the conventional wet-cut process—$1^1/_4$ in. (32 mm) maximum. The timing of the early-entry process, however, allows joints to be in place prior to development of significant tensile stresses in the concrete; this increases the probability of cracks forming at the joint when sufficient stresses are developed in the concrete. Care should be taken to make sure the early-entry saw does not ride up over hard or large coarse aggregate. The highest coarse aggregate should be notched by the saw to ensure the proper function of the contraction joint. State-of-the-art early-entry saws have an indicator that shows the operator if the saw cut becomes too shallow.

Typically, joints produced using conventional processes are made within 4 to 12 hours after the slab has been finished in an area—4 hours in hot weather to 12 hours in cold weather. For early-entry dry-cut saws, the waiting period will typically vary from 1 hour in hot weather to 4 hours in cold weather after completing the finishing of the slab in that joint location. Longer waiting periods can be necessary for all three types of sawing for floors with steel-fiber reinforcement or embedded-mineral-aggregate hardeners with long-slivered particles, such as traprock.

The depth of saw cut using a conventional saw should be at least $^1/_4$ of the slab depth or a minimum of 1 in. (25 mm), whichever is greater. The depth of saw cut using an early-entry dry-cut saw should be 1 in. (25 mm) minimum, unless experience has shown that a shallower saw cut is sufficient. This recommendation assumes that the early-entry dry-cut saw is used within the time constraints noted above. For steel-fiber-rein-

forced slabs, the saw cut using the conventional saw should be $^1/_3$ of the slab depth. Typically, experience has shown that when timely cutting is done with an early-entry saw, the depth can be the same as for plain concrete.

Regardless of the process chosen, saw cutting should be performed (1) before concrete starts to cool, (2) as soon as the concrete surface is firm enough not to be torn or damaged by the blade, and (3) before random-drying-shrinkage cracks can form in the concrete slab. Shrinkage stresses start building up in the concrete as it sets and cools. If sawing is unduly delayed, the concrete can crack randomly before it is sawed. Additionally, delay can generate cracks that run off from the saw blade toward the edge of the slab at an obtuse or skewed angle to the saw cut.

8.4—Finishing Class 1, 2, and 3 floors (tile-covered, offices, churches, schools, hospitals, ornamental, and garages)

The placing and finishing operations described under Section 8.3 should be followed. Multiple restraightening operations and two hand or machine trowelings are recommended, particularly if a floor is to be covered with thin-set flooring or resilient tile; this will give closer surface tolerances and a better surface for application of the floor covering.

The use of silica fume concrete for parking garage construction lends itself to a "one pass" finishing approach. After initial strikeoff and bull floating have been completed, the concrete placement strips can be textured using a broom. Normally, a light broom with widely-spaced, stiff bristles will be satisfactory for this purpose.

Since silica-fume concrete exhibits virtually no bleeding, it is necessary to keep the surface moist during concrete finishing operations to prevent plastic shrinkage cracking. This normally requires use of a pressure fogger with a reach capable of covering the entire surface. Fogging should be performed continuously between finishing operations until the surface has been textured. The goal of the fogging operation should be to keep the concrete surface moist, but not wet. It is critical that curing operations commence as quickly as possible after texturing has been completed.[29]

If decorative or nonslip finishes are desired, refer to procedures described in Section 8.13.

8.5—Finishing Class 4 and 5 floors (light-duty industrial and commercial)

The placing and finishing operations described in Section 8.3 should be followed. Three machine trowelings can be specified for increased wear resistance.

8.6—Finishing Class 6 floors (industrial) and monolithic-surface treatments for wear resistance

Floors using embedded mineral or metallic hardeners are usually intended for moderate or heavy traffic and, in some cases, to resist impact. It is essential that these hardeners be properly embedded near the top surface of the slab in order to provide the required surface hardness, toughness, and impact resistance.

Air content of the concrete should not be more than 3 percent if the concrete is not subject to freezing and thawing cy-

cles under service conditions. As with any commercial or industrial floor subjected to wheeled traffic, special care should be exercised to obtain flat and level surfaces and joints. Metallic hardeners should not be placed over concrete with chloride ion contents greater than 0.1 percent by weight of cementitious material. The proposed mixture proportions should be used in the installation of any test panel or test placement. If adjustments to the concrete mixture are required, they can be made at that time.

8.6.1 *Embedded mineral-aggregate hardener*—The application and finishing of embedded mineral-aggregate hardeners should follow the basic procedures outlined below. Concrete installations are subject to numerous conditions and variables. Experience is necessary to determine proper timing for the required procedures. It is recommended that these procedures be discussed and agreed upon at the preconstruction meeting:

1. Place, consolidate, and strike off concrete to the proper grade.

2. Compact and consolidate the concrete surface using a bull float.

3. Restraighten the surface using a modified highway straightedge. Occasionally, compacting, consolidating, and restraightening are accomplished in one step by using a wide bull float or a modified highway straightedge with the straightedge rotated so its wide dimension is in contact with the surface.

4. Evenly distribute approximately two-thirds of the specified amount of mineral-aggregate hardener immediately following the restraightening operation, and prior to the appearance of bleed water on the slab surface. The first application generally consists of a larger, coarser material than will be used in the final application. Distribution of the hardener by mechanical spreader is the preferred method. The concrete mixture should have proportions such that excessive bleed water does not appear on the surface after application of the hardener.

5. As soon as the hardener darkens slightly from absorbed moisture, a modified highway straightedge should be used to embed the hardener as well as to remove any irregularities in the surface.

6. Wait until the concrete sets up sufficiently to support the weight of a power trowel with float shoes or a pan attached. *Combination blades should not be used.* The float breaks the surface and agitates concrete paste at the surface of the slab. The first power-float passes should be across the placement strip in the short direction. This will ensure that irregularities resulting from the power floating can be easily identified and corrected in subsequent operations.

7. Apply the remaining one-third of the specified mineral aggregate, preferably at right angles to the first application. This material generally consists of finer-size aggregate and is most often broadcast over the surface of the slab by hand.

8. Restraighten the surface using a modified highway straightedge. Remove irregularities and move excess material to low spots.

9. Embed the mineral-aggregate fines using a power trowel with float shoes or a pan attached.

10. Restraighten the surface following the power-floating operation using a weighted modified highway straightedge if its use is seen to be effective or necessary to achieve required surface tolerances. One method of increasing the weight of a modified highway straightedge is to wedge a #11 bar inside the rectangular section of the straightedge.

11. Continue finishing with multiple power trowelings as required to produce a smooth, dense, wear-resistant surface (Section 8.3.11). Provide a burnished (hard) troweled surface where required by specification.

12. Cure immediately after finishing by following the curing material manufacturer's recommendations. Curing methods should be in accordance with those used and approved in construction of any test panel.

8.6.2 *Metallic dry-shake hardeners and colored dry-shake hardeners*—Metallic dry-shake hardeners and colored dry-shake hardeners can be finer in texture than uncolored-mineral-aggregate-dry-shake hardeners. This difference, along with the fact that the metallic dry-shake hardener has a higher specific gravity, dictates that the material normally be embedded in the concrete later in the setting process than is common for uncolored-mineral-aggregate-dry-shake hardeners. Some metallic dry-shake hardeners are designed by their manufacturers to allow application of all the hardener at one time. When such procedures are used, however, caution should be exercised to ensure that manufacturer's recommendations are followed, and that the material is thoroughly wetted-out, since a one-time application significantly increases the possibility of surface delamination or related finishing problems. Typical installation techniques for metallic dry-shake hardeners and colored dry-shake hardeners are similar to those described in Section 8.6.1, but the following sequence is recommended: Refer to Section 8.13.1 for additional discussion.

1. Place, consolidate, and strike off concrete to the proper grade.

2. Compact and consolidate the concrete surface using a bull float.

3. Restraighten the surface using a modified highway straightedge. A wide bull float or a modified highway straightedge can be used to accomplish both steps in one operation.

4. Open the surface to promote movement of bleed water to the top of the slab by using a wooden bull float. Steps 3 and 4 can be accomplished in one operation if the wide bull float or modified highway straightedge is made of wood.

5. Wait until the concrete sets up sufficiently to support the weight of a power trowel.

6. Break the surface using a power trowel with float shoes or a pan attached.

7. Evenly distribute approximately two-thirds of the specified amount of metallic dry-shake hardener or colored dry-shake hardener. Application of the material by mechanical spreader is the preferred method.

8. Restraighten the surface after application of the metallic dry-shake hardener or colored dry-shake hardener to remove irregularities. Some contractors find that embedding the ma-

terials and restraightening can be accomplished in one step using a modified highway straightedge.

9. Complete initial embedment and prepare the surface for additional material by using a power trowel with float shoes or a pan attached.

10. Apply the remaining one-third of the specified amount of metallic dry-shake hardener or colored dry-shake hardener, preferably at right angles to the first application.

11. Embed metallic dry-shake hardener or colored dry-shake hardener using a power trowel with float shoes or a pan attached. *Thorough embedment and integration of the metallic dry-shake hardener or colored dry-shake hardener with the concrete by floating is very important.* Failure to accomplish this goal can result in blistering or delamination of the slab.

12. Restraighten the surface following the power-floating operation using a weighted modified highway straightedge, if effective.

13. Continue finishing with multiple power trowelings as required to produce a smooth, dense, wear-resistant surface (Section 8.3.11). Proper and uniform troweling is essential. Colored surfaces should not be burnished—hard-troweled; the result would be uneven color and a darkening of the surface.

14. Cure immediately after finishing by following the curing material manufacturer's recommendations. Curing methods should be in accordance with those used and approved in construction of any test panel. Colored floors should not be cured with plastic sheeting, curing paper, damp sand, or wet burlap. These materials promote uneven color, staining, or efflorescence.

8.7—Finishing Class 7 floors (heavy-duty industrial)

The topping course of heavy-duty industrial floors should have a minimum thickness of $^3/_4$ in. (19 mm). The concrete topping used should have a maximum slump of 3 in. (75 mm) unless a water-reducing admixture or high-range water-reducing admixture is used to increase the slump, or unless dewatering techniques are used. Because of the relatively small amount of concrete in the topping course and the low slump required, concrete for the topping could be job-mixed.

Embedded metallic dry-shake hardeners, mineral-aggregate dry shakes, and colored dry-shakes can be applied to produce the desired combination of increased wear resistance or color as described in Sections 8.6.1 and 8.6.2, respectively.

The base course should be screeded and bull floated; close maintenance of the elevation tolerance for the base course surface is important. Class 7 floors can be constructed in two ways: (1) the topping installation can be bonded monolithically to the base slab before the base slab has completely set, or (2) the topping can be deferred for several days.

For suspended slabs, it is recommended that the deferred bonded approach be used. This will allow the structure to deflect under its own weight prior to application of the topping. The additional weight of the topping will have little impact on subsequent deflection of the slab.

8.7.1 *Bonded monolithic two-course floors*—For these floors, the topping course is placed before the base course has completely set. Any excess moisture or laitance should be removed from the surface of the base course, and the surface floated before the top course is placed. When the topping is being placed, the concrete in the base slab should be sufficiently hard that footprints are barely perceptible. The use of a disk-type power float can be necessary to bring sufficient past to the surface to allow restraightening to take place. The power-floating operation should be followed by a minimum of two power trowelings. This method of topping application is generally not appropriate for a suspended slab.

8.7.2 *Deferred bonded two-course floors*—Caution: *Bonding of two-course floors is a highly critical operation requiring the most meticulous attention to the procedure described.* Even with such care, such bonding has not always been successful. As a result, it is recommended that contractors using this type of construction for heavy-duty industrial applications be experienced and familiar with the challenges presented.

Locations of joints in the base course should be marked so that joints in the topping course can be placed directly over them.

After the base course has partially set, the surface should be brushed with a coarse-wire broom. This removes laitance and scores the surface to improve bond of the topping course.

It is recommended that concrete base courses be wet-cured a minimum of 3 days (Sections 9.2.1 and 9.2.2). Shrinkage-compensating concrete base courses should be wet-cured a minimum of 7 to 10 days, and preferably until the topping is applied. Refer to ACI 223 for additional information.

If the topping is to be applied immediately after the minimum 3-day curing time has elapsed, the curing cover or water should be removed from the slab and any collected dirt and debris washed or hosed off. After most free water has evaporated or has been removed from the surface, a bonding grout should be scrubbed in. The bonding grout should be composed of one part cement, 1.5 parts fine sand passing the No. 8 sieve (2.36 mm), and sufficient water to achieve the consistency of thick paint. The grout should be applied to the floor in segments, keeping only a short distance ahead of the concrete topping placing operations that follow it.

While the bonding grout is still tacky, the topping course should be spread and screeded. The use of a disk-type power float is suggested, followed by a minimum of two power trowelings.

If 3 to 7 days are to elapse between placing the base and the topping course, the surface of the base course should be protected from dirt, grease, plaster, paint, or other substances that would interfere with the bond. Immediately before placing the topping, the base course should be thoroughly cleaned by scrubbing with a brush and clean water. Most excess water should be removed and a thin coat of grout, as described previously, scrubbed in. While this grout is still tacky, the topping course should be spread and screeded, as described previously.

If the floor is to be subjected to construction activities after curing and before application of the topping, more thorough cleaning can be necessary. One method of cleaning the base

slab is to scrub the surface with water containing detergent. If oil or grease has been spilled on the floor, a mixture of sodium metasilicate and resin soap is useful. If this method is used, the floor should then be rinsed thoroughly with water. Shot-blasting, sand-blasting, or mechanical scarification by scabbling can also be employed in lieu of cleaning with detergent to achieve a bondable surface.

In some circumstances, it can be convenient or desirable to bond the topping with an epoxy adhesive appropriate for the particular application. Methods are described in ACI 503R, and a standard specification is given in ACI 503.2.

Joints in the topping above the joints in the base slab should be saw-cut to a depth equal to twice the thickness of the topping, and should match the location of joints in the base slab, where applicable.

8.8—Finishing Class 8 floors (two-course unbonded)

The unbonded topping for Class 8 floors should be a minimum of 4 in. (100 mm) thick. An unbonded topping thickness of 3 in. (75 mm) has been used with some success for Class 3 floors, but thickness for strength and control of curling is less important for a Class 3 slab because of its duty, loading, and because it may also be covered. A Class 8 floor is intended for industrial applications where strength and control of curling is more important. The base course, whether old or new, should be covered with plastic sheet, felt, a sand cushion, or other approved bond-breaker, spread as wrinkle-free as possible.

The topping slab should contain sufficient steel reinforcement to limit the width of shrinkage cracks in the topping and the displacement of the topping concrete on either side of any cracks that might form. Although reinforcing steel is normally discontinued at joints, engineering considerations can make it desirable to carry reinforcement through construction joints in specified locations in a topping. Reinforcement that is continuous through contraction and construction joints will cause restraint against movement that will inevitably result in cracks in the concrete.

Concrete for the top course should comply with the requirements of Table 6.2.1.

Power floats and power trowels are recommended and usually required. The practice of completing troweling by hand is counterproductive because hand troweling is less effective than power troweling in compacting the surface.

Embedded mineral-aggregate hardeners for increased wear resistance can be applied as described in Section 8.6.1.

Embedded metallic dry-shake hardeners and colored dry-shake hardeners can be applied as described in Section 8.6.2.

8.9—Finishing Class 9 floors (superflat or critical surface tolerance required)

Floor surfaces of this quality can be subdivided by function into two separate groups. Refer to Section 8.9.1 for special considerations dealing with construction of Class 9 floor surfaces.

The more common group of these floor surfaces should support vehicular traffic along paths that are defined prior to construction and that do not change during the life of the floor surface (that is, defined traffic). A typical example of a defined-traffic floor would be a distribution center that uses very-narrow aisles and high-bay racking systems. In this type of facility, tolerances across aisles and the joints that parallel them are less critical than those along the axis of the aisle. This type of floor surface is often referred to as "superflat."

Floor surfaces in the second group are less common, but should support traffic in all directions (that is, random traffic). A typical example of a random-traffic floor would be a television or movie studio. The random nature of traffic in these facilities requires that tolerances across placement strips and their joints should match those achieved parallel to the axis of the strip.

Finishing procedures required to produce Class 9 floors represent the most rigorous and demanding floor installation technology now being performed. If discipline and preplanning are a part of the overall process, however, installation of Class 9 floors is neither complex nor especially difficult. Proper timing and execution of various procedures will usually ensure that the floor produced is of a predictable quality.

Class 9 floor construction requires that (1) the slabs be constructed in long strips less than 20 ft (6 m) in width; (2) the concrete slump be adjusted onsite to within $\pm \, ^1/_2$ in. ($\pm$ 13 mm) of the target slump; (3) the slump at point of deposit be sufficient to permit use of the modified highway straightedge to close the floor surface without difficulty after the initial strikeoff; (4) the "window of finishability" be sufficient for the concrete contractor to perform the necessary finishing operations; and (5) the concrete supplier use enough trucks to ensure an uninterrupted concrete supply. In addition, since environmental factors can significantly alter the setting rate of concrete, an effort is usually made to construct Class 9 floors out of the weather.

On Class 9 defined-traffic floors, construction joints between placement strips are located out of the traffic pattern where racks abut each other. These surfaces are evaluated by taking measurements only in locations matching the wheel-paths of the vehicles that will eventually use the floor. The part of the floor surface falling under racks is not tested.

While the same construction techniques are required to produce Class 9 random-traffic floors—television studios or similar surfaces—the entire floor surface should be evaluated because the entire surface will be subjected to traffic. *The contractor is cautioned that grinding of the entire length of the joints will be necessary to produce Class 9 quality across the width of concrete placement strips.*

On most projects with Class 9 defined-traffic floors, surfaces are measured for flatness and levelness immediately following the final troweling of each placement; placements are frequently scheduled for consecutive days. Where Class 9 random-traffic quality should be achieved across multiple strips, initial testing should take place as each strip is placed, but final testing should be deferred until the installation is complete.

Nonetheless, it is imperative that surface-profile testing and defect identification be accomplished on each new slab as soon as possible. To maintain satisfactory results, the con-

tractor requires continuous feedback to gage the effectiveness of construction techniques against ever-changing job conditions (Section 8.9.1).

Achieving Class-9-quality levels on suspended slabs is impractical in a one-course placement. Deflection of the surface between supports occurs after removal of supporting shores. If the surface were to meet Class 9 requirements in a shored condition, it is very likely that the deflected surface after shores are removed would be less level than is required to meet Class 9 requirements. Two-course placements utilizing methods similar to those discussed for Class 7 and Class 8 floors provide the best opportunity for achieving Class-9-quality levels on suspended floors.

8.9.1 *Special considerations for construction of Class 9 floor surfaces*—Certain specialized operations—narrow-aisle warehouses, ice rinks, television studios, and air-pallet systems—require extraordinarily flat and level floors for proper equipment performance. Such superflat floors generally exhibit F_F numbers and F_L numbers above 50 in the direction of travel for the particular application. Refer to Section 8.15 for additional discussion.

The floor-finish tolerance employed in the contract specification should meet the equipment supplier's published requirements unless there is reason to doubt the validity of such requirements. In any case, written approval of the contract floor tolerance should be obtained from the appropriate equipment supplier prior to finalizing the bid package. In this way, equipment warranties will not be jeopardized, and the special superflat nature of the project will be identified to key parties from the outset.

Superflat floors have very specific design requirements. Chief among these is the limit imposed on placement width. In general, superflat floors cannot be produced if construction joint spacing exceeds 20 ft (6 m). Since hand-finishing procedures and curling effects are known to make floors in the vicinity of construction joints less flat than in the "middle" of the slab, joints should be located out of the main traffic areas, or provision should be made for their correction. Contraction joints oriented transverse to the longitudinal axis of a Class-9-placement strip can curl and reduce surface flatness along aisles. Limited placement width, consequent increased forming requirements, and reduced daily-floor production are primary factors that increase the cost of Class 9 floors.

The prebid meeting is an essential component of any superflat project. Since floor flatness/levelness is one of the primary construction requirements, a thorough prebid review of the design, specification, and method of compliance testing is required. This will enable the prospective contractor to price the project realistically (thereby avoiding costly misunderstandings and change orders), and will greatly increase the chances of obtaining the desired results at the lowest possible cost.

To further reduce the risk of significant problems, the installation of test slabs has become a standard part of superflat-floor construction. Generally, if the contractor is inexperienced with superflat construction or with the concrete to be used, at least two test slabs should be installed and

approved before the contractor is permitted to proceed with the balance of the superflat-floor construction.

Superflat-floor tolerances should be inspected within 24 hours after slab installation. This eliminates the possibility of large areas being placed before any tolerance problem is discovered. In narrow-aisle warehouses, tolerances are measured using a continuous recording floor profileograph or other device. In these facilities, floor tolerances are generally written around the lift-truck wheel dimensions, and compliance measurements and corrections are required only in the future wheel tracks.

In television studios and other similar random-traffic installations, the use of F_F and F_L to specify the floor-surface tolerances is appropriate. Measurements for compliance should be made in accordance with ASTM E1155 (Section 8.15).

8.10—Toppings for precast floors

Many types of precast floors require toppings. These include double-tees, hollow-core slabs, and other kinds of precast floor elements. When these floors are to be covered with bonded or unbonded toppings, the procedures in Section 8.7.2 or 8.8 should be followed as appropriate. High-strength concrete is often used for precast floor elements; roughening of the surface of such members can be difficult if delayed too long.

8.11—Finishing structural lightweight concrete

This section concerns finishing structural lightweight concrete floors. Finishing very-lightweight insulating-type concretes—having fresh weights of 60 lb per cu ft (960 kg/m^3) or less—that are sometimes used below slabs generally involves little more than screeding.

Structural lightweight concrete for floors usually contains expanded shale, clay, slate, or slag coarse aggregate; expanded shale is most common. The fine aggregate can consist of manufactured lightweight sand, natural sand, or a combination of the two, but natural sand is most common. The finishing procedures differ somewhat from those used for a normal weight concrete; in lightweight concrete, the density of the coarse aggregate is generally less than that of the sand and cement. Working the concrete has a tendency to bring coarse aggregate rather than mortar to the surface. This should be taken into account in the finishing operations.[39]

Observing the following simple rules will control this tendency so that structural lightweight concrete can be finished as easily as normal weight concrete, provided the mixture has been properly proportioned:

1. The mixture should not be over-sanded in an effort to bring more mortar to the surface for finishing. This usually will aggravate rather than eliminate finishing difficulties.

2. The mixture should not be under-sanded in an attempt to meet the unit weight requirements. Neither mixing to the recommended slump nor entrainment of air will effectively control segregation in such a mixture.

3. The lightweight-concrete mixture should be proportioned to provide proper workability, pumpability, finishing characteristics, and required setting time, to minimize segre-

gation or the tendency for coarse-aggregate particles to rise above the heavier mortar.

4. Some lightweight aggregates can require further control of segregation or bleeding, or both. For this purpose, use not less than 4 percent entrained air in accordance with ACI 211.2.

5. Presaturate lightweight aggregates for use in concrete that will be pumped, in accordance with the manufacturer's recommendations.

6. Overworking or over-vibrating lightweight concrete should be avoided. A well-proportioned mixture can generally be placed, screeded, and bull floated with approximately half the effort considered good practice for normal weight concrete. Excess darbying or bull floating are often principal causes of finishing problems, since they only serve to drive down the heavier mortar that is required for finishing, and to bring an excess of the coarse aggregate to the surface.

7. A magnesium darby or bull float should be used in preference to wood. Metal will slide over coarse aggregate and embed it rather than tear or dislodge it.

8. The surface should be floated and flat troweled as soon as surface moisture has disappeared and while the concrete is still plastic. If floating is being done by hand, use a magnesium float. If evaporation is not taking place soon enough (while concrete is still plastic), other measures should be taken. Water and excess moisture should be removed from the surface with as little disturbance as possible. A simple but reliable method is to drag a loop of heavy-rubber garden hose over the surface.

8.12—Nonslip floors

Nonslip surfaces are produced by using the following finishing procedures: swirl or broom finish (Section 8.13.4), or nonslip special-purpose aggregate (Section 8.13.2). The nonslip special-purpose aggregate is recommended for heavy-foot traffic.

References 40 and 41 describe methods of measuring and evaluating the relative skid resistance of floors.

8.13—Decorative and nonslip treatments

8.13.1 *Colored dry-shake-hardener surface treatment—* The installation of a colored surface treatment is particularly sensitive to the finishing and curing techniques employed by the contractor. It is recommended that sample panels be constructed prior to beginning actual placement on the project in order to confirm that the proposed procedures are adequate, and that the uniformity of color is acceptable. Any sample panel should be larger than 100 sq ft (9 m^2) and should be prepared using the concrete mixture and finishing and curing techniques planned for the project.[42]

Coloring agents are normally included with an embedded hardener when a hardener is applied and color is desired. Finishing procedures should follow the steps described in Section 8.6.2.

8.13.2 *Nonslip monolithic surface treatment—*Before being applied to the surface, the slip-resistant material (Section 5.4.8) should be mixed with dry portland cement if not already so formulated. Proportions usually range from 1:1 to

1:2; but the manufacturer's directions should be followed. The nonslip monolithic surface treatment procedure is the same as that outlined for the colored treatment (Section 8.6.2). A swirl finish produced using natural or colored embedded mineral or metallic hardeners provides increased wear resistance and also produces a long-lasting, nonslip finish (Section 8.13.1).

8.13.3 *Exposed aggregate surface treatment—*Exposed aggregate surfaces are commonly used to create decorative effects. Both the selection of the aggregates and the techniques employed for exposing them are important to the effect obtained; test panels should be made before the job is started. Colorful, uniform-sized gravel or crushed aggregate is recommended.

Aggregates should not be reactive with cement (ACI 201.2R). Aggregates can be tested by using ASTM C 227, or by petrographic examination (ASTM C 295). If information or a service record is lacking, the aggregates and the cement aggregate combinations should be evaluated using the guideline in the appendix to ASTM C 33.

Flat particles, sliver-shaped particles, and particles smaller than $^1/_4$ in. (6 mm), do not bond well. As a result, they can easily become dislodged during the operation of exposing the aggregate. The use of aggregate ordinarily used in concrete is not satisfactory unless the aggregate is sufficiently uniform in size, bright in color, and can be closely packed, and uniformly distributed.

Immediately after the slab has been screeded, and darbied or bull floated, the selected aggregate should be broadcast and evenly distributed so that the entire surface is completely covered with one layer of the select aggregate. Initial embedding of the aggregate is usually done by patting with a darby or the broad side of a short piece of 2- x 4-in. (50- x 100-mm) lumber. After the aggregate has been thoroughly embedded and as soon as the concrete will support the weight of a finisher on kneeboards, the surface should be floated using a magnesium hand float, darby, or bull float until aggregate is entirely embedded and slightly covered with mortar. This operation should leave no holes in the surface.

Shortly after floating, a reliable surface set retarder can be sprayed over the surface in accordance with the manufacturer's recommendations. Retarders may not be necessary on small jobs, but they are generally used on large jobs to ensure better control of the exposing operations. Use of a surface set retarder ordinarily permits several hours to elapse before brushing and hosing the surface with water exposes the aggregate. It is important to note that the proper timing for exposing the aggregate is critical whether or not a retarder has been used, and this timing is very dependent upon the temperature and other weather conditions. Recommendations of the retarder manufacturer should be followed closely.

Operations to expose the aggregate should begin as soon as the surface can be brushed and washed without overexposing or dislodging the aggregate. If it becomes necessary for finishers to move about on the newly exposed surface, kneeboards should be used, gently brought into contact with the surface, and neither slid nor twisted on it. If possible,

however, finishers should stay off the surface entirely because of the risk of breaking the aggregate bond.

If a smooth surface is desired, as might be the case in an interior area, no retarder should be used. The aggregate is not exposed until the surface has hardened. Exposure is accomplished after hardening entirely by grinding. If grinding is followed by polishing, a terrazzo-like surface can be produced.

Alternative methods of placement are available. A top course, 1 in. (25 mm) or more thick, that contains the select aggregate can be applied, or the monolithic method can be used. The monolithic method does not use aggregate seeding; the select aggregate to be exposed is mixed throughout the concrete during batching.

Tooled joints are not practical in exposed-aggregate concrete because the aggregate completely covers the surface. Decorative or working joints are best produced by wet-cut sawing (Section 8.3.12). Another method of providing joints is to install permanent strips of wood (redwood, cypress, or cedar) before placing concrete (Fig 3.2.5.3.a).

Exposed-aggregate slabs should be cured thoroughly. Care should be taken that the method of curing does not stain the surface. Straw, earth, and any type of sheet membrane, such as polyethylene or building paper, can cause discoloration (Section 9.2.2).

8.13.4 *Geometric designs, patterns, and textures*—Concrete surfaces are frequently scored or tooled with a jointer to produce various decorative patterns. For random geometric designs, the concrete should be scored after it has been screeded, bull floated or darbied, and excess moisture has left the surface. Scoring can be done using a jointer, a groover, or a piece of pipe bent to resemble an S-shaped jointer tool. The tool is made of $^1/_2$- or $^3/_4$-in. (15- or 19-mm) pipe, about 18 in. (450 mm) long. Cobblestone, brick, tile, and many other patterns can be impressed deeply into partially-set concrete slabs with special imprinting tools (Reference 42). See PCA's *Finishing Concrete Slabs with Color and Texture* (PA 124M) for patterned concrete.

A swirl-float finish or swirl design can be produced using a magnesium or wooden hand float, or a steel finishing trowel. After the concrete surface has received the first power-float pass and subsequent restraightening using a modified highway straightedge, a float should be worked flat on the surface in a semicircular or fanlike motion using pressure. A finer-textured swirl design can be obtained with the same motion by using a steel finishing trowel held flat. An alternative method is to draw a soft-bristled broom across the slab in a wavy motion.

After the concrete has set sufficiently that these surface textures or patterns will not be marred, the slab should be moist-cured. Plastic membranes or waterproof curing paper should not be used on colored concrete (Sections 9.2.1 and 9.2.2).

8.14—Grinding as a repair procedure

Grinding can be used to repair certain surface defects. Grinding has been used successfully to repair the following kinds of problems:

1. Unacceptable flatness and levelness

2. Curled joints

3. Surface irregularities that might show through thin floor coverings, such as resilient tile

4. Poor resistance to wear, when this is due to a weak floor surface with sound concrete underneath

5. Rain damage

8.14.1 *Cautions*—Grinding does not always produce the desired effect, and it sometimes makes the floor look worse. It can also adversely affect the floor's resistance to wear, particularly in industrial applications where the surface is subject to heavy traffic and abuse. For these reasons, it is usually wise to make a small trial section before starting full-scale repairs. Only wet grinding should be used, primarily to minimize dust, and also because diamond-disk grinders are more effective when used with water.

8.14.2 *Types of grinders*—Many types of grinders are available. The two types most often used on floor slabs are diamond-disk grinders and stone grinders.

8.14.2.1 *Diamond-disk grinder*—This grinder uses one or more diamond-impregnated steel disks. Each disk is mounted horizontally and is driven by a vertical shaft. The most common type of diamond-disk grinder has a single 10-in. (250-mm) grinding disk powered by a gasoline engine or electric motor of 5 to 10 hp (3.7 to 7.4 kW). Bigger, more powerful machines are available for floors that need extensive grinding. Diamond-disk grinders are much faster than stone grinders, and are usually the better choice to correct Problems 1 and 2 above.

8.14.2.2 *Stone grinder*—This grinder uses multiple abrasive blocks, called stones, mounted on one or more steel disks. The abrasive material is usually silicon carbide. The most widely used type of stone grinder has two disks with three stones on each disk. One-disk and four-disk machines are also available. Stone grinders can be effective on Problems 3 through 5 above, particularly where the floor surface is soft, or where the amount of material to be removed is small.

8.15—Floor flatness and levelness

8.15.1 *Floor flatness/levelness tolerances*—Tolerances for various floor uses should conform to the requirements set forth in ACI 117. A discussion of floor flatness/levelness is given in the commentary to ACI 117.

ACI 117 specifies that overall conformance to design grade shall be within $^3/_4$ in. (19 mm) of design elevation. For suspended cast-in-place concrete slabs, this tolerance is to be achieved before removal of any supporting shores. For suspended slabs on metal deck, this tolerance for overall conformance to design grade does not apply, since tolerances for erected steel frames are not consistent with those for formwork in cast-in-place concrete frames.

8.15.1.1 *F-number system*—It is recommended that both flatness and levelness requirements be described by Face Floor Profile Numbers.[43] Two separate F-numbers are required to define the required flatness and levelness of the constructed floor surface. Refer to the Commentary on ACI 117 for additional discussion of this method.

FLATNESS/LEVELNESS TYPICAL USE GUIDE
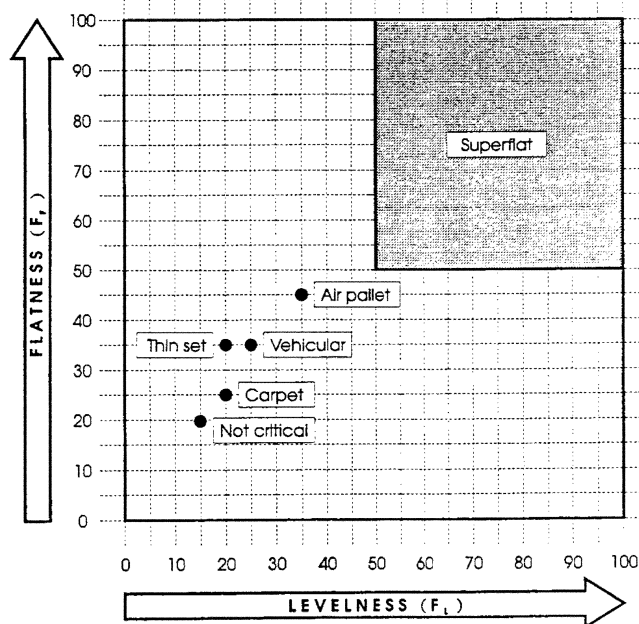
SLABS ON GRADE

Composite flatness (F_F)	Composite levelness (F_L)	Typical use	Typical class
20	15	Noncritical: mechanical rooms, nonpublic areas, surfaces to have raised computer flooring, surfaces to have thick-set tile, and parking structure slabs	1 or 2
25	20	Carpeted areas of commercial office buildings or lightly-trafficked office/industrial buildings	2
35	25	Thin-set flooring or warehouse floor with moderate or heavy traffic	2, 3, 4, 5, 6, 7, or 8
45	35	Warehouse with air-pallet use, ice, or roller rinks	9
>50	>50	Movie or television studios	3 or 9

SUSPENDED SLABS

Composite flatness (F_F)	Composite levelness (F_L)	Typical use	Typical class
20	15^2 or N/A	Noncritical: mechanical rooms, nonpublic areas, surfaces to have raises computer flooring, surfaces to have thick-set tile, and parking structure slabs	1 or 2
25	20^1 or N/A	Carpeted areas of commercial office buildings	2
30	20^2 or N/A	Surfaces to receive thin-set flooring	2, 3, or 4
>50	$>50^{1,3}$	Movie or television studios	3 and 9

NOTES:
1. Multidirectional quality of this level requires grinding of joints.
2. Levelness F-number only applies to level slabs shored at time of testing.
3. This levelness quality on a suspended slab requires a two-course placement.

Fig. 8.15.1.1

The Flatness F-number (F_F) controls local surface bumpiness by limiting the magnitude of successive 1-ft (300-mm) slope changes when measured along sample measurement lines in accordance with ASTM E 1155.

The Levelness F-number (F_L) controls local conformance to design grade by limiting differences in departures from design grade over distances of 10 ft (3 m) when measured along sample measurement lines in accordance with ASTM E 1155.

The F-number pair is always written in the order F_F/F_L. In theory, the range of flatness and levelness F-numbers extends from zero to infinity. In practice, F_F and F_L values generally fall between 12 and 45. The scale is linear, so the relative flatness/levelness of two different floors will be in proportion to the ratio of their F-numbers. For example, an F_F30/F_L24 floor is twice as flat and twice as level as an F_F15/F_L12 floor.

On random-traffic floors—those with varied and unpredictable traffic patterns—two tiers of specified F_F/F_L values should be indicated: one for the composite values to be achieved (Specified Overall Value), and one for the minimum quality level that will be accepted without repair (Minimum Local Value).

Compliance with the Specified Overall Value is based on the composite of all measured values. For any given floor, the composite F_F/F_L values are derived in accordance with ASTM E 1155, Section 9.10.

Minimum Local Values represent the minimum acceptable flatness and levelness to be exhibited by any individual floor section. Minimum Local Values are generally set at 67 percent of the Specified Overall Values, and are not normally set lower than 50 percent of the specified overall F_F/F_L requirements. Minimum Local Values should never be less than F_F13/F_L10, since these values represent the worst local results to be expected from any concrete floor construction method.

Remedial measures can be required:

 If the composite value of the entire floor installation (when completed) measures less than either of the specified overall F-numbers, or

 If any individual section measures less than either of the specified Minimum Local F_F/F_L numbers. Sectional boundaries are usually set at the column and half-column lines on suspended slabs, or at the construction and contraction joints for slabs on ground. They should be no closer together than one-half bay.

Remedial measures for slabs on ground might include grinding, planing, surface repair, retopping, or removal and replacement. For suspended slabs, remedial measures are generally limited to grinding or use of an underlayment or topping material. Contract documents should clearly identify the acceptable corrective method(s) to be used.

The selection of proper F_F/F_L tolerances for a project is best made by measurement of a similar satisfactory floor. This measurement is then used as the basis for the F_F/F_L tolerance specification for the new project. If this method is used, it is important to note that slab-on-ground floor surfaces change after construction as a result of shrinkage and curling, and that the surfaces of suspended slabs change as a

result of deflection. Because of these post-construction changes, it is likely that measurements of an existing project will yield results of a lower quality than can be achieved by the contractor because all of the post-construction changes just described create slightly diminished F_F/F_L measurement results. When measurement of a similar satisfactory floor is not possible or practical, the flatness/levelness quality levels provided in Figure 8.15.1.1 have been found to be reasonable for the stated applications.

8.15.1.2 *The 10-ft (3-m) straightedge method*—The older method of using a 10-ft (3-m) straightedge can also be used to measure floor flatness, but it is much less satisfactory than the F-number system. There is no nationally accepted method for taking measurements or for establishing compliance of a test surface using this tolerance approach. This lack of an accepted standard test procedure often leads to conflict and litigation. The straightedge-tolerance method also has a number of other serious deficiencies. Refer to the Commentary on ACI 117 for additional discussion.

When straightedge tolerances are specified, the Committee emphasizes that 100 percent compliance with 10-ft (3-m) straightedge tolerances is unrealistic. Compliance with four of five consecutive measurements is more realistic, with a provision that obvious faults be corrected.

8.15.1.3 *Other measurement methods*—Measurement methods are not limited to the F-number (ASTM E 1155) or the 10-ft (3-m) straightedge systems. Alternative tolerancing systems that adequately control critical floor surface characteristics can be used.

8.15.2 *Precautions*—Floor tolerance specification and measurement procedures are currently undergoing technological change. Much remains to be learned about which tolerances can be reasonably expected from a given construction method. On those projects where floor flatness/levelness constitutes a potential issue, the following precautions are suggested:

•The exact meaning of the flatness/levelness requirement, and the exact method and time of measurement to determine compliance, should be established prior to beginning construction.

•The contractor should confirm an ability to satisfy the floor tolerance requirement by profiling previous installations.

•Where feasible, test slabs should be installed to verify the effectiveness of proposed installation procedures under actual job conditions. If necessary, methods and procedures should then be modified for the actual job installation based on these results. The acceptance of the test slab by the owner as to tolerances and surface finish should clarify requirements for the project slab.

•The exact remedy to be applied to every possible floor tolerance deficiency should be confirmed.

8.15.3 *Factors influencing floor flatness and levelness*—The flatness and levelness exhibited by a newly installed concrete slab on ground will depend upon the effectiveness of the specific placement and finishing procedures employed during its construction. In general, the forming, placement, and initial strikeoff phases of the installation will establish

Flatness/Levelness (F_F/F_L) Construction Guide

Notes:
1. These descriptions illustrate typical tolerance levels and construction procedures for floor surfaces in which direction and location of traffic may vary (random-traffic pattern). Most surfaces must accommodate random-traffic patterns.
2. The use of F-numbers to specify tolerances allows the specifier and contractor independent control of surface waviness and levelness. The Flatness F-number (F_F) controls waviness; the Levelness F-number (F_L) controls local levelness.
   Flatness quality is primarily a function of finishing technique (tools and procedures used after initial strikeoff). Levelness quality is mainly dependent on accuracy of formwork and initial strikeoff.
3. The tolerance examples illustrate average to high floor tolerances; specified quality levels should be dictated by facility use.
4. Descriptions of placing and finishing methods are intended to assist the contractor in evaluation and "fine-tuning" of relative costs associated with producing the various levels of quality in flatness and levelness.
5. Finishing sequences described in this table require a slight modification when a metallic hardener, mineral-aggregate hardener, pigmented hardener, or pigment is to be applied. Refer to Section 8.6 for detailed discussion of suggested techniques. Proposed techniques for application of hardener and finishing concrete should be confirmed with a successful panel installation.

Table 8.15.3.a— Slabs on grade: flatness

Typical specification requirements	Typical finishing requirements
Specified overall value - 20 Minimum local value - 15	1. Smooth surface using 4 to 5 ft wide bull float. 2. Wait until bleed water sheen has disappeared. 3. Float surface with one or more passes using a power float (float-shoe blades or pans). 4. Make multiple passes with a power trowel (trowel blades).
Specified overall value - 25 Minimum local value - 17	1. Smooth and restraighten surface using 8 to 10 ft wide bull float. 2. Wait until bleed water sheen has disappeared. 3. Float surface with one or more passes using a power float (float-shoe blades or pans). 4. Restraighten surface following paste-generating float passes using 10 ft wide highway straightedge. 5. Make multiple passes with a power trowel (trowel blades).
Specified overall value - 35 Minimum local value - 24	1. Smooth and restraighten surface using 8 to 10 ft wide bull float. Apply in two directions at 45 deg angle to strip. 2. Wait until bleed water sheen has disappeared. 3. Float surface with one or more passes using a power float (float-shoe blades or pans). 4. Restraighten surface following paste-generating float passes using 10 ft wide highway straightedge. Use in two directions at 45 deg angle to strip. Use supplementary material to fill low spots. 5. Make multiple passes with a power trowel (trowel blades are preferable). 6. Restraighten surface after trowel passes using multiple passes with weighted highway straightedge to scrape the high spots. No filling of low spots is done at this stage.
Specified overall value - 50 Minimum local value - 35	1. Smooth and restraighten surface using 8 to 10 ft wide bull float or highway straightedge. Apply in two directions at 45 deg angle to strip. 2. Wait until bleed water sheen has disappeared. 3. Float surface with one or more passes using a power float (float-shoe blades or pans). First float pass should be across width of strip. 4. Restraighten surface following paste-generating float passes using 10 ft wide highway straightedge. Use in two directions at 45 deg angle to strip. Use supplementary material to fill low spots.

Table 8.15.3.a— Slabs on grade: levelness

Typical specification requirements	Typical forming and strikeoff requirements
Specified overall value - 15 Minimum local value - 10	1. Set perimeter forms (optical or laser instruments). 2. Use block placements of varying dimensions. Use wet screed strike-off techniques to establish initial grade.
Specified overall value - 20 Minimum local value - 15	1. Set perimeter forms (optical or laser instruments). 2. Use block placements of varying dimensions. Use wet screed strikeoff techniques to establish initial grade. 3. Check grade after strikeoff. Repeat strikeoff as necessary.
Specified overall value - 25 Minimum local value - 17	1. Set edge forms using optical or laser instruments. Optical instruments provide more accurate elevation control. 2. Use strip placements with maximum widths of 50 ft. Utilize edge forms to establish initial grade. 3. Use vibratory screed for initial strikeoff.
Specified overall value - 30 Minimum local value - 20	1. Set edge forms using optical or laser instruments. Optical instruments provide more accurate elevation control. 2. Use strip placements with maximum widths of 30 ft. Utilize edge forms to establish initial grade. 3. Use vibratory screed for initial strikeoff. 4. Check grade after strikeoff. Repeat strikeoff as necessary. 5. Use a laser screed in lieu of rigid strikeoff guides and vibratory screed to produce this same quality.
Specified overall value - 50 Minimum local value - 35	1. Set edge forms using optical instrument to $\pm^{1}/_{16}$ in accuracy. Use straightedge to identify form high spots; place top surface to fit inside $^{1}/_{16}$ in envelope. 2. Use strip placements with maximum widths of 20 ft. Utilize edge forms to establish initial grade. 3. Use vibratory screed for initial strikeoff. 4. Check grade after strikeoff. Repeat strikeoff as necessary. 5. Follow vibratory screed pass with two or three hand straightedge passes along the axis of the strip. 6. Use a laser screed in lieu of rigid strikeoff guides and vibratory screed to produce this same quality.

Table 8.15.3.b— Suspended slab: flatness

Typical specification requirements	Typical finishing requirements
Level and shored until after testing: 　Specified overall value - 20 　Minimum local value　-15 Unshored: 　Specified overall value - 20 　Minimum local value - 15	1. Smooth surface using 4 to 5 ft wide bull float. 2. Wait until bleed water sheen has disappeared. 3. Float surface with one or more passes using a power float (float-shoe blades or pans). 4. Make multiple passes with a power trowel (trowel blades).
Level and shored until after testing: 　Specified overall value - 25 　Minimum local value　-17 Unshored: 　Specified overall value - 25 　Minimum local value - 17	1. Smooth and restraighten surface using 8 to 10 ft wide bull float. 2. Wait until bleed water sheen has disappeared. 3. Float surface with one or more passes using a power float (float-shoe blades or pans). 4. Restraighten surface following paste-generating float passes using 10 ft wide highway straightedge. 5. Make multiple passes with a power trowel (trowel blades).
Level and shored until after testing: 　Specified overall value - 30 　Minimum local value　-24 Unshored: 　Specified overall value - 30 　Minimum local value - 24	1. Smooth and restraighten surface using 8 to 10 ft wide bull float. Apply in two directions at 45 deg angle to strip. 2. Wait until bleed water sheen has disappeared. 3. Float surface with one or more passes using a power float (float-shoe blades or pans). 4. Restraighten surface following paste-generating float passes using 10 ft wide highway straightedge. Use in two directions at 45 deg angle to strip. Use supplementary material to fill low spots. 5. Make multiple passes with a power trowel (trowel blades are preferable).
Level and shored until after testing: 　Specified overall value - 50 　Minimum local value　- 35 Unshored: 　Specified overall value - 50 　Minimum local value - 35	1. Smooth and restraighten surface using 8 to 10 ft wide bull float or highway straightedge. Apply in two directions at 45 deg angle to strip. 2. Wait until bleed water sheen has disappeared. 3. Float surface with one or more (float-shoe blades or pans). First float pass should be across width of strip. 4. Restraighten surface following paste-generating float passes using 10 ft wide highway straightedge. Use in two directions at 45 deg angle to strip. Use supplementary material to fill low spots. 5. Make multiple passes with a power trowel (trowel blades are preferable). 6. Restraighten surface after trowel passes using multiple passes with weighted highway straightedge to scrape the high spots. No filling of low spots is done at this stage.

Table 8.15.3.b— Suspended slab: levelness

Typical specification requirements	Typical forming and strikeoff requirements
Level and shored until after testing: 　Specified overall value - 15 　Minimum local value　-10 Unshored: 　Specified overall value - N/A 　Minimum local value - N/A	1. Set perimeter forms (optical or laser instruments). 2. Use block placements of varying dimensions. Use wet screed strikeoff techniques to establish initial grade.
Level and shored until after testing: 　Specified overall value - 20 　Minimum local value　-15 Unshored: 　Specified overall value - N/A 　Minimum local value - N/A	1. Set perimeter forms (optical or laser instruments). 2. Use block placements of varying dimensions. Use wet screed strikeoff techniques to establish initial grade. 3. Check grade after strikeoff. Repeat strikeoff as necessary.
Level and shored until after testing: 　Specified overall value - N/A 　Minimum local value　-N/A Unshored: 　Specified overall value - 50 　Minimum local value - 30	1. Use a two-course placement to achieve this levelness quality. Topping slab must be placed using slab on grade techniques after shoring has been removed. 2. Set edge forms using optical instrument to $\pm^1/_{16}$ in accuracy. Use straightedge to identify form high spots; place top surface to fit inside $^1/_{16}$ in envelope. 3. Use strip placements with maximum widths of 20 ft. Utilize edge forms to establish initial grade. 4. Use vibratory screed for initial strikeoff. 5. Check grade after strikeoff. Repeat strikeoff as necessary. 6. Follow vibratory screed pass with two or three hand straightedge passes along the axis of the strip.

Metric Equivalents

$^1/_{16}$ in = 1.5 mm
4 ft = 1.2 m
5 ft = 1.5 m
8 ft = 2.4 m
10 ft = 3 m
20 ft = 6.1 m
30 ft = 9.1 m
50 ft = 15.2 m

the floor's relative levelness, while subsequent finishing operations (floating, restraightening, and troweling) will determine the floor's relative flatness. Any factor that complicates placing or finishing operations will have an adverse effect upon the flatness/levelness produced.

The flatness and levelness F-numbers normally obtained using a given floor construction procedure are summarized in Tables 8.15.3.a and 8.15.3.b.

These are the floor-finish tolerances expected to be achieved by competent, knowledgeable finishers under "standard" job conditions. Difficult job environments could result in significantly lower values. Both specifiers and contractors should approach each new concrete floor project using the guidelines set forth in Section 8.15.2.

8.15.3.1 *Flatness*—On those projects where flatness is an important consideration, precautions should be taken to provide an adequate construction environment. Of particular concern for both slabs on ground and suspended slabs are:

- •Workability, finishability, and setting times of concrete to be used
- •The "window of finishability," which should be sufficient for the contractor to perform the required finishing operations
- •Sun, wind, rain, temperature, other exposure conditions, and their effects on personnel and concrete
- •Light levels
- •Timeliness of concrete delivery
- •Consistency of delivered slump
- •Consistency of final setting time
- •Site accessibility

8.15.3.2 *Levelness*—For slabs on ground, accuracy of formwork and initial strikeoff establish the overall levelness of the surface. Form spacing, therefore, is an important consideration when developing a construction program intended to produce a certain quality. The use of block-placement techniques with wet-screed strikeoff provides the least accurate control of grade. Block placements with moveable rigid-screed guides provides an improvement in the levelness quality that can be achieved. Further improvement in levelness generally requires the use of either strip placements and vibrating screeds, or self-propelled laser-guided strike-off equipment. Strip widths up to 50 ft (15.2 m) have provided levelness quality comparable to that which can be achieved using moveable dry-screeds in a block placement. Reducing the width of strips improves the ability of the contractor to produce level surfaces because there is less tendency for the vibrating screed to oscillate or deflect, and the controlling edge form elevations are closer together. The highest quality of levelness can be achieved using strip widths between 10 and 20 ft (3 and 6 m). This width allows the contractor to follow the vibrating screed with hand straightedging operations to remove any imperfections in the surface left by the vibrating screed.

Levelness of suspended slabs is dependent on accuracy of formwork and strikeoff, but is further influenced by behavior of the structural frame during and after completion of construction. Each type of structural frame behaves somewhat differently; it is important that the contractor recognize those

differences and plan accordingly. Refer to Chapter 3 for more detailed discussion of behavior of different types of structural systems.

The F_L levelness tolerance should only be applied to slabs on ground that are level and to suspended slabs that are both level and shored at the time data are taken. The F_L levelness tolerance should not apply to slabs placed on unsupported form surfaces. It should not be applied to cambered or inclined slab surfaces. Concrete slabs placed over unshored structural steel and metal deck surfaces can exhibit significant deflection in the hardened state. The resulting slab surfaces have occasionally required extensive repair to achieve a product satisfactory for applied finishes or partitions.

8.15.4 *Timeliness of tolerance measurement*—To establish the flooring contractor's compliance with specified floor tolerances, the contract documents should stipulate that floor tolerance compliance tests be performed and defective areas identified. This should be completed by the owner's agent as soon as possible, preferably within 24 hours after placement, and be reported to key parties as soon as possible, but not later than 72 hours after installation. For suspended cast-in-place slabs, tests for acceptance should be conducted before forms and shoring have been removed. In this way, the effects of deflection and shrinkage on the tolerance data can be minimized.

As a practical matter, measurements for suspended-slab construction should usually be made within a few hours of slab placement. In vertical construction, the only available surface for staging materials is often the slab that has just been placed and finished. Failure to take advantage of this very short window of availability following completion of finishing operations will hamper, if not preclude, the tolerance data collection.

Early measurement also relates directly to the contractor's performance. If methods and procedures require modification, changes can be made early on, minimizing the amount of unsatisfactory floor surface and repair required. At times, later measurements will be needed to see whether other influences have impacted flatness or levelness. For example, slabs on ground are subject to edge curling in the weeks following construction; cast-in-place suspended slabs deflect from their supported position when shores are removed. These possible later changes are affected by various design choices as well as the implementation of these choices by the contractor. For slabs on ground, such design choices include slab thickness, joint spacing, use of reinforcing steel, and vapor retarders. Inadequate curing can also accelerate curling of slabs on ground. For cast-in-place suspended slabs, deflection can be influenced by a number of variables, including depth of the structure, quantity of reinforcing steel, form-stripping procedures, and concrete strength when shoring is removed.

Since curling of slabs on ground will adversely affect flatness/levelness in service, methods to limit curling (Section 11.11) should be identified in the contract documents. Concrete with the lowest practical water content and low-shrinkage characteristics should be required. In addition, base conditions should not be such that the concrete underside re-

mains wet while the top dries out. Joint spacings, load transfer device, and reinforcement should be designated to minimize curling. Proper curing measures are essential, and should be started as soon as possible after final finishing. These requirements should be clearly defined in the contract documents and adhered to during the concreting operations.

8.16—Treatment when bleeding is a problem

Prolonged bleeding can occur with poorly-proportioned mixtures, poorly-graded aggregates, excessive slump, or under conditions of low temperature, high humidity, or no air circulation. Bleed water may not evaporate, and the surface may not be sufficiently dry for floating and troweling.

One method to remedy the problem is to use fans or blower heaters of adequate size and in sufficient numbers to evaporate the excess moisture while the concrete is still plastic. Avoid using nonvented heaters, particularly those impinging on the surface of new concrete. They will cause carbonation of the surface, which can create a soft, dusty, chalky surface (Section 11.4).

If the concrete is firm enough for floating, but the surface is still wet, the following methods can be used to obtain a drier surface:

1. Drag a rubber hose slowly over the entire surface; the concrete should be stiff enough so that only water is removed. In limited small areas that are difficult to reach with a hose, a single pass of a trowel tipped on edge can be used to remove water; however, slowly dragging a hose is much less likely to damage the surface, and this method should be used for the problem whenever possible.

2. Where required after removal of bleed water, apply additional concrete to fill low spots. This can be accomplished by discharging a small amount of concrete in a container during placing operations. The material in the container should have setting characteristics similar to those of the in-place concrete.

In general, the bleeding tendencies of concrete can be reduced significantly by the following actions. Every reasonable effort should be made to take such measures when bleeding is a problem:

1. Correct any aggregate gradation deficiency problem where materials of the required size gradations are economically available. The use of gap-graded aggregates results in increased bleeding. Ideally, combined gradation of all aggregates should yield a percent retained on each sieve below the largest and above the No. 100 (150 μm) of somewhere between 8 percent and 18 percent. The most common deficiency is in the $^3/_8$ in., No. 4, No. 8, or No. 16 (9.5 mm, 4.75 mm, 2.36 mm, or 1.18 mm) sieve sizes.

2. Use more cement if paste content is low.

3. Use pozzolan to replace part of cement or as an addition to the cement. (Note: Pozzolan should be finer than cement, and if the pozzolan is fly ash, it should conform to the requirements of ASTM C 618.)

4. Use the maximum allowable amount of entrained air. The use of air-entrained concrete containing in excess of 3 percent air for hard-troweled surfaces can promote development of blisters, delamination, and surface peeling.

5. Increase the amount of fine aggregate passing the No. 50, 100, and 200 (300, 150, and 75 μm) sieves to near the maximum allowable amount. More water (and possibly more cement) can be needed due to more paste being required; more shrinkage could result.

6. Use the lowest practicable water content.

7. Avoid admixtures that augment bleeding.

8. Use an accelerating admixture (see Section 5.6.3 for potentially deleterious effects).

9. Use concrete approaching the highest as-placed temperature permitted by the contract documents. (Note: Except for bleeding, there are benefits to be derived from placing concrete at the lowest permissible temperature.)

10. Use dewatering techniques (Section 8.3.6).

8.17—Delays in cold-weather finishing

Since concrete sets more slowly in cold weather and can be damaged by freezing, measures should be taken to keep the concrete temperature above 50 F (10 C). Appropriate curing procedures (Section 9.5.1) should be provided to prevent moisture loss and to keep every portion of the slab (including the edges) above freezing temperature. Any of the concrete's tendencies toward bleeding will be considerably aggravated by the slower setting, and more work will be required to take care of it properly (Section 8.16). Many extra hours of finishers' time will be required unless acceptable means can be found to shorten the setting time. Often, some extra expense to speed up the operation is justified by whichever of the following methods are most appropriate and least costly for a particular situation. Before adopting any method, tests should be made with job materials at job temperature conditions to confirm that acceptable results will be obtained.

1. Where it can be used without violating the precautions of Section 5.6.3, a 1 percent to 2 percent addition of calcium chloride by weight of cement will accelerate setting significantly. When used, it should be added as a water solution.

2. Where the use of calcium chloride is prohibited:

  a. A change to high-early-strength cement (Type III), or use of a larger amount of Type I or II cement than usually required, can provide sufficient acceleration. Use of these modifications can modestly increase shrinkage and curling. Increases in cement content above approximately 600 to 625 lb per cu yd (355 to 370 kg/m^3) can cause additional drying shrinkage and cracking in the hardened concrete.

  b. Noncorrosive, nonchloride accelerating admixtures are available. The dosage rate can be varied to provide the optimum acceleration.

  c. An increase in concrete temperate to 70 F (21 C) will noticeably reduce the setting time (although a low as-placed concrete temperature has many benefits). ACI 306R.

  d. Early access for floating can be achieved by the application of dewatering techniques after first strikeoff and bull floating (Section 8.3.6).

3. The water-cementitious material ratio should be reduced and the minimum slump selected that can be easily handled and placed.

4. Overworking the concrete should be avoided during the strikeoff and bull-floating operations.

CHAPTER 9—CURING, PROTECTION, AND JOINT FILLING

9.1—Purpose of curing

After proper placement and finishing of suitable quality concrete, curing is the single most important factor in achieving a high quality slab. The primary purpose of curing is to slow the loss of moisture from the slab. A longer period of moisture retention permits more complete hydration of the cement, resulting in greater strength. See ACI 308 for details as to recommended curing time and minimum recommended temperatures.

9.2—Methods of curing

Moisture retention can be enhanced by several methods including moisture addition, moisture retaining covers, and liquid membrane-forming curing compound. The characteristics of curing materials are set forth in detail in Section 5.9.

9.2.1 *Water curing*—Water curing by ponding, sprinkling, or soaking should only be employed on slab areas without joints or where the water is positively confined by dams to prevent flooding the base course or saturating the sub-base/subgrade. This is necessary to limit potential slab curling due to moisture gradients and to preserve compaction of the soil support system. Water used for curing should closely match the concrete temperature at time of application. Fogging can provide the most satisfactory approach. Care should be taken to maintain continuous wetting and to prevent isolated dry spots. Water curing should be used for shrinkage-compensating concrete slabs.

9.2.2 *Wet covering*—When properly applied and maintained, burlap and other wet coverings provide a continuous supply of moisture uniformly distributed on the slab surface. Burlap has been the most commonly used wet covering; wet burlap tends to reduce the temperature of the hydrating concrete slabs. Moist hay, straw, earth, or sand have been used, but their use is usually too labor-intensive for large projects and can discolor the surface. If sand or earth is used, it should be applied at least 1 in. (25 mm) deep and kept continuously wet during the curing period. Wet coverings should be laid over the concrete as soon as finishing operations are complete and surface marring can be avoided. Exposed concrete edges should be carefully covered. The coverings should be kept wet so that a film of moisture remains continuously in contact with the concrete throughout the curing period. Burlaps are available that resist rot and fire or that reflect light—reducing heat absorption from sunlight—or a combination thereof. Coverings with burlap on one side and polyethylene on the other are also available; the polyethylene is helpful in keeping the burlap moist longer, but it makes rewetting more difficult.

9.2.3 *Moisture retaining coverings*—Although not usually as effective as water curing and wet coverings, moisture retaining coverings are widely used due to their convenience.

9.2.3.1 *Polyethylene (plastic) film*—Polyethylene film and other plastic sheet materials are available in clear, white, or black and are easily handled; the white is especially good for covering fresh concrete subject to sunlight. These films avoid leaving a residue that can prevent the bond of new concrete to hardened concrete or the bond of resilient floor coverings to concrete. Plastic films are particularly effective for curing the base slab of two-course floors. However, they can leave blotchy spots on the slab and should not be used for colored concrete or where appearance of the slab surface is important. The sheets should be spread as soon as possible after finishing operations without marring the surface finish. Edges of sheets should be lapped a sufficient distance to prevent moisture loss and sealed with tape, mastic, or glue, or held in place with wood planks or sand. Construction traffic should be restricted because the film can be extremely slippery.

9.2.3.2 *Waterproof paper*—Waterproof paper has the same advantages and disadvantages as plastic film, except that discoloration is less likely. It should be light in color; the edges should be lapped and sealed, and left in place for the duration of the curing period. Tears caused by construction traffic should be repaired to maintain proper moisture retention.

9.2.4 *Liquid membrane-forming curing compounds*—Application of liquid membrane-forming curing compounds is the most widely used method for curing concrete. Advantages are relatively low in-place cost, early access to the floor, and the elimination of subsequent monitoring of the curing process. Disadvantages include the potential for insufficient and uneven coverage, conflict with regulations on the release of volatile organic compounds, interference with bond of surfacing materials, and variability of quality and solids content. Liquid membrane-forming curing compounds should be applied as soon as finishing operations are complete, while the surface is still damp, but without free water. Machine spraying is preferable, but manual spraying is acceptable if accomplished with sufficient care to ensure uniform and complete coverage. White-pigmented or fugitive-dye compounds help assure even coverage and can be considered to reflect light and heat for floors exposed to sunlight. Generally, the curing compound should meet or exceed the minimum moisture retention requirements of ASTM C 309 (Section 5.9.3).

Curing compounds leave a film that can interfere with the adhesion of other materials to the treated surface; they should not be used on the base slab of a bonded two-course floor. Their use should also be avoided on surfaces that will later be covered with resilient floor coverings, protective coatings, sealers, or other special treatments. Where applicable, a letter of compatibility should be issued prior to the use of a curing compound on a floor receiving a subsequent finish. Curing compounds can also aggravate tire marking problems from forklift traffic; special nonmarking tires can be effective in minimizing these problems.

9.3—Curing at joints

It is important that edges of joints be cured to ensure maximum concrete strength and further reduce the potential for curling. Joints are cured adequately when wet coverings or moisture-retaining coverings are used. If a liquid membrane-forming curing compound is used, it may have to be removed later if a joint filler is installed. Alternatively, joints can be temporarily filled with wet sand or compressed backer rod during the curing period. If sand is used, it should be rewetted periodically.

9.4—Curing of special concretes

Colored concretes and metallic-hardened floors require special curing techniques. Refer to Section 8.6 and recommendations of the materials manufacturer.

9.5—Length of curing

Regardless of the method employed, the curing process should begin as soon as finishing operations are complete. If concrete begins to dry excessively prior to completion of finishing operations, the surface should be protected by fogging or use of a monomolecular film. The duration of curing will vary with the method, ambient temperature, humidity, and type of cement. With any type of cement, in temperatures above 40 F (5 C) 7 days of uninterrupted curing is normally recommended for water curing or moisture-retaining-cover curing. This time period can be reduced to 3 days when high-early-strength concrete is used and temperatures are 73 F (23 C) or higher.

9.5.1 *Cold-weather considerations*—Slabs should not be placed on a frozen base. Cold-weather protective measures should maintain a concrete temperature above 50 F (10 C), and appropriate curing procedures should be provided to minimize moisture loss. Insulating blankets placed over the top of a curing membrane will retain heat, provided there is no danger of serious loss of heat from below the slab—for example, an upper floor of an open, unheated building. Particular care should be given to the corners and edges of the slab, which are more vulnerable to rapid heat loss. The amount of insulation required can be calculated from tables furnished in ACI 306R. When there is a danger of freezing—particularly when mean daily temperatures are lower than 40 F (4 C)—insulation is frequently not sufficient to protect thin slabs of concrete used for floors, and auxiliary heat is required. The area should be enclosed with tarpaulins or plastic sheeting and heated with live steam or vented heaters. The use of salamanders, or other equipment that exhaust carbon dioxide gases into the area above the concrete floor, should be avoided because of the danger of carbonation of the fresh concrete; carbonation will result in a soft, dusty surface.[21]

Where freezing is anticipated during or within a few days following the curing period, consideration should be given to protection of the concrete. Concrete saturated with water is vulnerable to freezing damage; the use of thermal blankets or other protective measures can be necessary. The curing method and procedure should cure the concrete satisfactorily and allow appropriate drying of the concrete be-

fore freezing. See Section 4.6 for other concrete placement conditions and refer to ACI 306R for more information on cold-weather concreting procedures.

9.5.2 *Hot-weather considerations*—In hot weather, curing procedures should begin immediately following or even before the final finishing operations to prevent surface drying. Continuous moist-curing methods—water curing and wet coverings—are the most effective because they provide adequate moisture and tend to prevent excessive heat build-up. Moisture-retaining coverings limit evaporation; conditions creating temperature gradients in the slab should be avoided. Curing compounds used for exterior work should be white-pigmented. See Section 4.6 for other concrete placement conditions, and refer to ACI 305R for more information on hot-weather concreting procedures.

9.6—Preventing plastic shrinkage cracking

Plastic shrinkage cracking occurs in newly floated or troweled slabs when the rate of drying at the surface is more rapid than the upward movement of bleed water. Plastic shrinkage cracking occurs in the presence of such factors as moderate to high winds, low relative humidity, and high concrete and air temperatures. The use of latex-modified concrete, high-range water reducers, and silica fume tends to increase plastic shrinkage cracking potential since these materials usually reduce the bleed rate of concrete.

Vapor retarders/barriers immediately under the concrete may aggravate plastic and drying-shrinkage cracking and slab curling because the bottom of the slab loses little or no moisture while the top dries and shrinks at a faster rate.[6,7,8]

If the rate of water evaporation from the concrete exceeds 0.2 lb per sq ft per hr (1.0 kg/m^2/hr), precautions should be taken to reduce evaporation (Fig. 2.1.5 of ACI 305R). Measures helpful in preventing or reducing plastic shrinkage cracking are given in Section 11.2.1; additional information is presented in ACI 305R.

9.7—Curing after grinding

If grinding is required, it should be initiated as soon as the floor is hard enough to avoid dislodging aggregate particles. Curing should be maintained both before and after early grinding.

9.8—Protection of slab during construction

Protection should be provided against:
  a. Heavy construction traffic
  b. Hard-wheeled traffic
  c. Impact and abrasion
  d. Imposed loads (cranes, concrete trucks)
  e. Stains (grease, oil, chemicals, paints, plaster, clay soil)
  f. Rubber tire marks
  g. Deicers
  h. Freezing

9.9—Temperature drawdown in cold storage and freezer rooms

The temperature reduction in freezer and cold storage rooms should be gradual to control cracking caused by dif-

differential thermal contraction and to allow drying to remove excess moisture from the slab after curing. A typical drawdown schedule might be as follows:

	Temperature	Time
1. Ambient to 35 F (1.7 C)	10 F (5.6 C)	Per day (24 hours)
2. Hold at 35 F (1.7 C)	——	2 to 5 days
3. 35 F (1.7 C) to final	10 F (5.6 C)	Per day

9.10—Joint filling and sealing

Materials for joint fillers and sealants are discussed in Section 5.12. Construction and contraction joints are normally formed and sawn, or sawn only. Saw cuts should not be made at the construction joints until a crack is perceptible where the adjacent placements abut each other. Isolation joints can be formed with preformed fiberboard, polyethylene foam, or similar materials before concrete placement begins. This is described in Section 3.2.5.1 and detailed in ACI 504R. Backer rods should not be used in joints that will be exposed to heavy traffic. Isolation joints are sometimes sealed with an elastomeric sealant to prevent moisture, dirt, or debris accumulation.

9.10.1 *Time of filling and sealing*—Concrete slabs on ground continue to shrink for years; most shrinkage takes place within the first year. It is advisable to defer joint filling and sealing as long as possible to minimize the effects of shrinkage-related joint opening on the filler or sealant. This is especially important where semirigid epoxy fillers are used in traffic-bearing joints; such epoxies have minimal extensibility. If the joint should be filled before most of the shrinkage has occurred, separation should be expected between the joint edge and the joint filler, or within the joint filler itself. These slight openings can subsequently be filled with a low-viscosity epoxy adhesive. If construction traffic dictates that joints be filled early, provisions should be made to require that the contractor return at a preestablished date to complete the necessary work using the same manufacturer's product. Earlier filling will result in greater separation, and will lead to the need for more substantial correction; this separation does not indicate a failure of the filler. For cold storage and freezer room floors, the joint filler should be installed only after the room has been held at its planned operating temperature for 48 hours.

9.10.2 *Installation*—Elastomeric sealants should be installed over a backer rod or other bondbreaker as described in ACI 504R. The use of elastomeric sealants over backer rods is not recommended in joints exposed to solid-wheel traffic. Semirigid epoxy and polyurea fillers should be installed full-depth in saw-cut joints. Joints should be suitably cleaned to provide optimum contact between the filler or sealant and bare concrete. Vacuuming is recommended rather than blowing the joint out with compressed air. Dirt, debris, saw cuttings, curing compounds, and sealers should be removed. Cured epoxy fillers should be installed flush with the floor surface to protect the joint edges and re-create an interruption-free floor surface.

CHAPTER 10—QUALITY CONTROL CHECKLIST

10.1—Introduction

The Committee recommends that details on a Quality Control Program be included in the contract documents. To ensure that the program will be fully complied with for the duration of the project, procedures should be presented to the involved parties in the prebid meeting, and reviewed in detail at the preconstruction meeting. Since the eventual success of any project is the result of a team effort, there should be a complete understanding and agreement regarding the provisions of the Program before any concrete construction is started.

Many items involved with quality control will be covered in the preconstruction meeting, but some questions or concerns will invariably come up on site that are not covered in the bid documents or at the meeting. Therefore, it is essential to have a person on site who has the experience and background necessary to use the best possible judgment. Personnel with ACI certification can contribute greatly toward resolving these concerns, as well as ensuring quality construction in the field.

10.2—Partial list of important items to be observed

Additional background information regarding important items such as concrete reinforcement, surface hardeners, and joint sealants can be applicable during the actual construction phase.

10.2.1 *Slump control and testing*—The addition of water to the concrete at the jobsite (Section 7.3.2) can be required to ensure consistent placeability, workability, and finishability; it is essential that no more water be added than is necessary to meet the overall project requirements. The Committee recommends that a specific amount of "trim water"—part of the design mix water—be withheld at the plant to permit this onsite adjustment. Two procedures that help ensure adequate control of slump at the jobsite are: (1) be sure truck mixers come to the site with full water tanks, and (2) designate one specific person to authorize adding water at the site.

Testing, including provisions for handling and storing cylinders or cores, should be completed in accordance with ASTM procedures. This is particularly significant when air-entrained concrete is used; the actual air content is subject to change and requires repeated testing. When entrained air is prohibited, or less than 3 percent total air is desired, the air content should be checked on the first truck, and occasionally thereafter.

10.2.2 *Avoid delays*—Anything that would result in slump loss should be avoided—delays in delivery of concrete, delays in placing or finishing operations, and interruptions by other trades. Although the mixture proportions may have been approved, some minor adjustments could be required due to locally available materials or jobsite conditions.

10.2.3 *Forms, reinforcement, dowels, and joints*—Forms, reinforcement, and dowels should be secured and remain straight and true during the entire placing and finishing operation. Unless otherwise stated in the contract documents, reinforcement should be discontinued at joints. If the contract documents indicate that reinforcement should continue through joints, the engineer should be told that some random

cracking could result. The alignment of reinforcement along joints should permit a straight sawcut to be effective and allow joints to open. Smooth dowels should be used in joints where load transfer is required. Dowels in contraction joints should be positively supported and aligned. Any conditions that create restraint to the normal shrinkage process should be noted—for example, the condition of the base on which the concrete is placed. Although the practice of cutting every other bar or wire has been used with some success, there is always the possibility of some cracks forming in the intermediate panels due to partial restraint at the joint (Section 3.2.4).

10.2.4 *Finishing*—The finishing process should be discussed with the finishing foreman since no specification can be sufficiently accurate as to the actual timing of most finishing operations. Slab edges should be given special attention, beginning with the initial floating step and continuing through the entire finishing process.

If an aggregate- or metallic-surface hardener is used, the hardener should be completely "wetted out" so no dry material will be floated into the surface prior to machine floating.

10.2.5 *Curing, saw cutting, joint filling, and tolerances*—The proposed method of curing, the necessary timing for sawing joints, the protection of joint edges until the joints are filled, the timing of joint filling, and the protection required of the completed floor should be reviewed in detail. There should be a complete understanding regarding the order in which the curing, sawing, and floor tolerance testing are to be performed.

10.2.6 *On-site meeting*—After initial placement, it is possible that additional onsite meetings may be necessary to review actual results and discuss any required adjustments in the overall plan. Also, backup procedures for equipment breakdowns should be discussed with the concrete superintendent—for example, pumps, troweling machines, spreaders, and saws.

CHAPTER 11—CAUSES OF FLOOR AND SLAB SURFACE IMPERFECTIONS

11.1—Introduction

Concrete is a forgiving material. But, concrete quality can be adversely affected by conditions over which the engineer or the contractor has little control. This chapter lists the conditions and circumstances that can cause imperfections in concrete floor and slab surfaces. Concrete is capable of providing a highly durable, serviceable, and attractive surface. When it does not do so, there are always reasons. By keeping the causes of certain imperfections in mind, it is possible to reduce the likelihood of unsatisfactory results; these causes will be described briefly in this chapter. When the corrective action to eliminate a particular cause is not obvious, the most promising suitable procedure described in preceding chapters will be referenced.

In reviewing the causes of floor and slab surface imperfections, the reader should keep in mind the inherent characteristics of portland cement concrete, such as drying shrinkage cracking. Some curling and cracking can be expected on ev-

ery project. Also, it will be evident that the most common imperfections stem from failure to obey the basic rules of concrete finishing given in Section 8.3.3, such as "Any finishing operation performed while there is excess moisture or bleed water on the surface will cause dusting or scaling" [and also cause crazing and reduced resistance to wear]; and as is stated in Section 8.3.5, "No subsequent operation [after bull-floating and restraightening] should be done until the concrete will sustain foot pressure with only about $1/4$-in. (6-mm) indentation" [that is, no premature finishing].

Another common cause of floor and slab surface imperfections is the lack of prompt curing. The keyword is "prompt," and the degree to which this can be accomplished, especially in dry or windy weather, will improve the quality of floor and slab surfaces tremendously. Moist curing is best, provided the slab is kept continuously moist (Section 9.2).

Rarely will there be a single cause for a given imperfection; usually some combination will be responsible. The influence of any cause will vary with the degree of its departure from best practice, with the properties of the materials used, and with the ambient temperature and other weather conditions present during the work. Satisfactory results are more likely to be obtained if the causes mentioned for the various kinds of imperfections are carefully avoided.

11.2—Cracking

Cracking of concrete (Fig. 11.2) is a frequent complaint. Cracking is caused by restraint (internal or external) of volume change, commonly brought about by a combination of factors such as drying shrinkage, thermal contraction, curling, settlement of the soil support system, and applied loads. Cracking can be significantly reduced when the causes are understood and preventive steps are taken. For example, joints that are properly designed, detailed, and installed at the proper spacing and time during construction will cause cracks to occur in the joints, where they remain inconspicuous, instead of random locations.

Contractors are not necessarily responsible for all cracks. Many floor or slab design features and concrete mixture proportions are responsible for, or contribute to, cracking of concrete construction. If a contractor believes there are prob-

Fig. 11.2—Drying shrinkage cracks such as these are a frequent cause of complaint

Fig. 11.2.2.1—Plastic shrinkage cracks are caused by rapid loss of mix water from the surface while the concrete is still plastic

Fig. 11.2.2.2—Crazing is a network of very fine superficial surface cracks

lems with slab design, mixture proportions, or other problems, they should be pointed out prior to installation; the prebid and preconstruction meetings should be used for this purpose. Designers should pay careful attention to the causes of cracking, and contractors need to understand floor and slab design and concrete mixture proportioning in order to avoid problems. Designers also should understand slab construction in order to avoid "building in" problems for the contractor. For more information on control, causes, evaluation, and repair of cracks in concrete structures, see ACI 224R and 224.1R.

11.2.1 *Restraint*—Since cracking is caused by restraint of volume changes, normal volume changes would be of little consequence if concrete were free of any restraint. But, since concrete in service is usually restrained by foundations, subgrade, reinforcement, or connecting members, significant stresses can develop—particularly tensile stresses. The amount of drying shrinkage will be reduced somewhat by taking practical measures to place the concrete with the lowest possible water content. Water reduction through use of admixtures—water-reducing admixtures meeting ASTM C 494, Types A and D, and air-entraining admixtures—has little effect on drying shrinkage.[1,28,44] Thus, drying shrinkage of concrete containing water reducers can still result in undesirable cracking unless the following poor practices are prevented:

1. Contraction joints spaced too far apart (Section 3.2.5.3).
2. Contraction joints not deep enough.
3. Contraction joints not sawn early enough.
4. Slabs strongly restrained at their perimeters by bond of floor or slab concrete to foundation walls or other construction, or by tying-in reinforcement to foundations, docks, and tilt-up walls (Section 3.2.5).
5. Isolation joints not provided around columns (Figs. 3.2.5.1.a and 3.2.5.1.b).
6. Omission of joint or omission of extra reinforcing steel placed diagonally to reentrant corners.
7. Concrete mixtures of low strength with too little cement, too much water, or both. Also, mixtures that include any ingredient, such as aggregates or admixtures, with high-shrinkage characteristics.
8. Deficient curing, or no curing.

9. Slabs restrained by a rutted or uneven base, and changes in slab thickness.
10. Reinforcement continuous through joints, thus preventing joints from opening.
11. Slabs cast upon a base which has a high coefficient of friction, such as an open-graded crushed stone. Such bases can be "choked-off" with a $^1/_2$-in.-thick (13-mm) layer of sand or a suitable fine-graded crushed-stone material. This will provide a smoother surface on which the slab can slide (Section 4.1.4).

11.2.2 *Early cracking*—Some cracking can occur before the concrete has hardened. This can complicate the finishing operations considerably. Some examples are:

1. Plastic-shrinkage cracking (Sections 9.6 and 11.2.2.1). Plastic-shrinkage cracks in the still-unhardened concrete can sometimes be closed by tamping and beating the surface with a hand float. While this should be done, the more effective protective measures listed in Section 11.2.2.1 also should be undertaken immediately to remove the causes of plastic-shrinkage cracking in the remaining work.
2. Cracking from settlement of concrete around reinforcing bars or other embedments (Sections 5.8 and 6.2.5).
3. Cracking along edges where forms are not rigid.
4. Early thermal cracking.
5. Damage from form removal.

11.2.2.1 *Plastic-shrinkage cracking*—Plastic-shrinkage cracks (Fig. 11.2.2.1) are relatively short, shallow, random (but sometimes parallel) cracks that can occur before final finishing on days when wind, low humidity, and high concrete and ambient temperatures occur. Surface moisture evaporates faster than it can be replaced by rising bleed water, causing the surface to shrink more than the interior concrete. As the interior concrete restrains shrinkage of the surface concrete, stresses that exceed the concrete's tensile strength develop, resulting in surface cracks. These cracks range from a few inches to a few feet (about 100 mm to 1 m or more) in length. They can be roughly parallel to one another and spaced from a few inches to two feet (about 100 to 600 mm) apart, but usually occur in a random, irregular pattern. Crack formation begins at the surface and continues downward for some distance, rapidly becoming narrower

with depth. Though usually only a few inches (approximately 25 to 75 mm) deep, they can go completely through the slab. Following are some helpful measures to prevent or reduce plastic-shrinkage cracking:

1. Dampen the base when no vapor retarder is used.
2. Erect windbreaks.
3. Erect sunshades.
4. Cool aggregates and mixing water before mixing.
5. Prevent rapid drying by one of the following:
   a. Protect concrete with moisture-retaining coverings (Section 9.2.3) during any delay between placing and finishing.
   b. Cover with damp burlap or with white-polyethylene sheeting (Section 9.2.2) immediately after screeding and bull-floating. Keep burlap moist until the concrete is ready for finishing. Uncover only a small area at one time, just ahead of the finishers. Begin curing as soon as possible.
   c. Use monomolecular films to reduce evaporation between the various placing and finishing operations.
   d. Use a fog spray located upwind of the freshly-placed concrete. The spray device should use metered heads and discharge spray into the air above the concrete.
6. Postpone each step of finishing (and its inherent reworking of the surface) as long as possible without endangering results.
7. Avoid the use of a vapor retarder where not needed.

11.2.2.2 *Crazing*—Crazing, a pattern of fine cracks that do not penetrate much below the surface, is caused by minor surface shrinkage (Fig. 11.2.2.2). Crazing cracks are very fine and barely visible, except when the concrete is drying after the surface has been wet. They are similar to mud cracking in shape and in generation. The cracks encompass small concrete areas less than about 2 in. (50 mm) in dimension, forming a chicken-wire-like pattern. The term "map cracking" is often used to refer to cracks that are similar to crazing cracks only more visible and involving larger areas of concrete. Although crazing cracks can be unsightly and can collect dirt, crazing is not structurally serious and does not necessarily indicate the start of future deterioration in interior slabs.

When concrete is just beginning to gain strength, climatic conditions, particularly the relative humidity during the drying period in a wetting and drying cycle, are an important cause of crazing. Low humidity, high air and concrete temperatures, hot sun, or drying wind, either separately or in any combination, can cause rapid surface drying that encourages crazing. The conditions that contribute to dusting, as described in Section 11.4, also will increase the tendency to craze.

To prevent crazing, curing procedures should begin immediately—within minutes after final finishing, particularly after hard troweling. This is especially important when weather conditions are adverse. When the temperature is high, and the sun is shining with high winds and low humidity, some method of moist curing should be used to stop rapid drying. The concrete should be protected against rapid changes in temperature and moisture wherever feasible. Other conditions to be avoided that can cause craze cracking are:

1. Curing with water that is more than 20 F (11 C) cooler than the concrete.
2. Alternate wetting and drying of the concrete surface at early ages.
3. Overuse of jitterbugs, vibrating screeds, and bull floats (Section 8.3.2).
4. Overworking and overtroweling, especially when the surface is too wet (Sections 8.3.10 and 8.3.11).
5. Premature floating and troweling (Section 8.3.3).
6. Dusting dry cement onto a surface to hasten drying before finishing.
7. Too much clay and dirt in aggregates.
8. Sprinkling water onto the surface of a slab during finishing.

11.2.3 *Other causes*—Cracking can result from causes other than shrinkage. Prominent causes are:

1. Uneven support by a poorly prepared subgrade, subbase or base, poor drainage, or uneven support due to curling of slab edges (Section 11.11).
2. Expansive clay in the subgrade.
3. Sulfates in subgrade soil or groundwater.
4. Placing concrete over preformed joint filler (when placing adjacent concrete).
5. Improper jointing and sealing (Sections 3.2.5, 5.12, 9.10, and ACI 504R).
6. Structural overloading, especially following the floor construction phase of a building project.
7. Impact loads.
8. Disruption from expansive alkali-silica reaction.
9. Disruption from corrosion of reinforcing steel.
10. Disruption from freezing and thawing along edges and at corners.
11. Earth movements from contiguous construction—for example, blasting or pile driving.
12. Thermal contraction, such as a sharp drop in ambient temperature shortly after casting a floor or slab.
13. Early or excessive construction traffic.
14. Improper design (for example, selection of an inadequate safety factor), resulting in a slab of inadequate thickness for service conditions.

11.3—Low resistance to wear

Low wear resistance is due primarily to low-strength concrete, particularly at the surface. Such low strengths result from:

1. Too much mixing water.
2. Use of concrete with too high a water-cementitious material ratio.
3. Excessive slump, which promotes bleeding and carries softer, lighter-weight material (laitance) to the surface. After considering the unavoidable causes for slump loss, use the lowest practical water content and slump (Table 6.2.1).
4. Overworking overwet concrete. This should not be construed to mean that it is acceptable to use overwet concrete under any conditions. Whatever is placed must be worked, but if concrete is overwet, the ready-mix plant should be called to make sure no more wet batches are delivered. In addition to producing a surface with low resistance to wear,
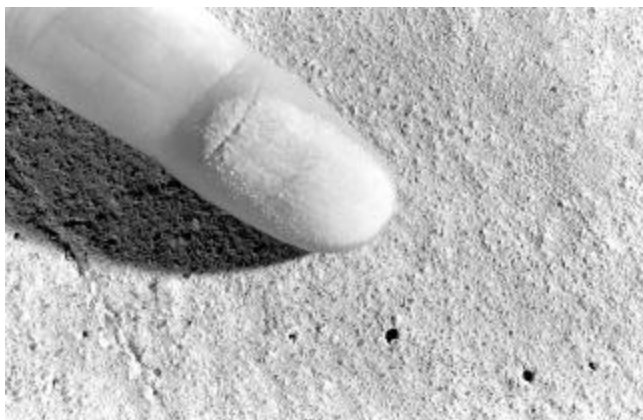
Fig. 11.4—Dusting is evident when a fine powdery material can be easily rubbed off the surface of a slab

Fig. 11.5—Scaling is the loss of surface mortar, usually exposing the coarse aggregate

overworking of overwet concrete also will cause segregation; fluid mortar will flow into low areas, settle, and leave low spots.

5. Premature floating and troweling, which works bleed water into the surface (see Section 8.16 if bleeding is a problem).

6. Excessive use of water by finishers (Section 8.3.3).

7. Excessive entrained air in the surface mortar (although occurrence of this is not common).

8. Deficient curing (Chapter 9).

9. Surface carbonation from unvented heaters used for cold-weather protection (ACI 306R).

10. Impairment of surface strength potential by early-age freezing (ACI 306R).

11. Opening slab to abrasive traffic before sufficient strength has developed.

12. Poor finishing techniques and improper timing during and between finishing operations (Section 8.3).

11.4—Dusting

Dusting (Fig. 11.4) is another aspect of weak concrete at the surface of a floor or slab. Dusting (the development of a fine, powdery material that easily rubs off the surface of hardened concrete) can occur either indoors or outdoors, but is more likely to be a problem when it occurs indoors. Dusting is the result of a thin, weak surface layer, called laitance, which is composed of water, cement, and fine particles.

Fresh concrete is a fairly cohesive mass, with the aggregates, cement, and water uniformly distributed throughout. A certain amount of time must elapse before the cement and water react sufficiently to stiffen and develop hardened concrete. During this period, the cement and aggregate particles are partly suspended in the water. Because the cement and aggregates are heavier than water, they tend to sink. As they move downward, the displaced water and fines move upward and appear at the surface, resulting in more water and fines near and at the surface than in the lower portion of the concrete. This laitance—the weakest, most permeable, and least wear-resistant material—is at the top surface, exactly where the strongest, most impermeable, and most wear-re-

sistant concrete is needed. Floating and troweling concrete with bleed water on the surface mixes the excess water back into the surface, further reducing the strength and wear resistance at the surface, and giving rise to dusting (Section 8.3.3). Dusting can also be caused by:

1. Overly wet mixes with poor finishing characteristics.

2. Insufficient cement (Table 6.2.4).

3. Excessive clay, dirt, and organic materials in the aggregate.

4. Use of dry cement as a blotter to speed up finishing.

5. Water applied to the surface to facilitate finishing.

6. Carbonation of the surface during winter concreting, caused by unvented heaters (ACI 306R).

7. Inadequate curing, allowing rapid drying of the surface, especially in hot, dry, and windy weather.

8. Freezing of the surface (ACI 306R).

11.5—Scaling

Scaling is the loss of surface mortar and mortar surrounding the coarse aggregate particles (Fig. 11.5). The aggregate is usually clearly exposed and often stands out from the concrete. Scaling is primarily a physical action caused by hydraulic pressure from water freezing within the concrete; it is not usually caused by chemical corrosive action. When pressure exceeds the tensile strength of concrete, scaling can result if entrained-air voids are not present in the surface concrete to act as internal pressure relief valves. The presence of a deicing solution in water-soaked concrete during freezing causes an additional buildup of internal pressure. However, properly designed and placed air-entrained concrete will withstand deicers for many years.

Deicers such as sodium chloride, urea, and weak solutions of calcium chloride do not chemically attack concrete; *however, deicers containing ammonium sulfate or ammonium nitrate will rapidly disintegrate concrete and should not be used*. Several deicers, particularly those containing chloride ions, can accelerate corrosion of embedded steel. Prominent among the causes of scaling are:

1. Permeable and poor-quality concrete due to:

   a. High water-cementitious material ratio (over 0.50).

    b. Excessive slump for prevailing job conditions (Table 6.2.1).

    c. Overworking of wet concrete (Section 8.3.10).

    d. Premature finishing operations (Section 8.3.3).

    e. Inadequate curing (Chapter 9).

    f. Low compressive strength at the surface (Section 6.2.3).

  2. In concrete to be exposed to freezing and thawing in service, little or no entrained air due to

    a. Failure to use an air-entraining agent.

    b. Air worked out by overworking overwet concrete in premature finishing operations (Sections 8.3.10 and 8.3.3).

    c. Air content too low due to: mixing too long, concrete temperature too high for a given dosage of air-entraining agent, or improper dispensing of air-entraining agent.

  3. Air content too low to resist the effect of chemicals used for snow and ice removal (Section 6.2.3).

  4. Inadequate thermal protection, allowing freezing of the surface at an early age.

  5. Exposure of new concrete to freezing and thawing before it has been adequately cured, achieved a compressive strength of 4000 psi (28 MPa), and allowed to air dry. Application of deicing chemicals at this early age greatly increases the likelihood of scaling.

  6. Blistering (Section 11.7), which increases vulnerability to scaling.

  7. Inadequate slope to properly drain water away from the slab; saturated concrete is more susceptible to damage from freezing and thawing than drier concrete.

11.5.1 *Mortar flaking*—Mortar flaking over coarse aggregate particles (Fig. 11.5.1) is another form of scaling. Aggregate particles with flat surfaces are more susceptible to this type of imperfection than round particles. Mortar flaking occasionally precedes more widespread surface scaling, but its presence is not necessarily an indication of an onslaught of more extensive scaling.

  Mortar flaking over coarse aggregate particles is caused essentially by the same actions that cause regular scaling and often results from placing concrete on hot, windy days. Excessive and early drying out of the surface mortar can alone aggravate scaling; however, the moisture loss is accentuated over aggregate particles near the surface because bleed water beneath the aggregates cannot readily migrate to the surface to replenish the evaporated water. This combination of bleed-water blockage, high rate of evaporation, and lack of moisture necessary for cement hydration results in a dry-mortar layer of low strength, poor durability, high shrinkage, and poor bond with the aggregate. Upon freezing in a saturated condition, this thin, weakened mortar layer breaks away from the aggregate. Poor finishing practices can also aggravate mortar flaking.

11.6—Popouts

  Popouts are roughly cone-shaped pits left in the surface of flatwork after a small piece of concrete has broken away by internal pressure (Fig. 11.6). This pressure is generated by
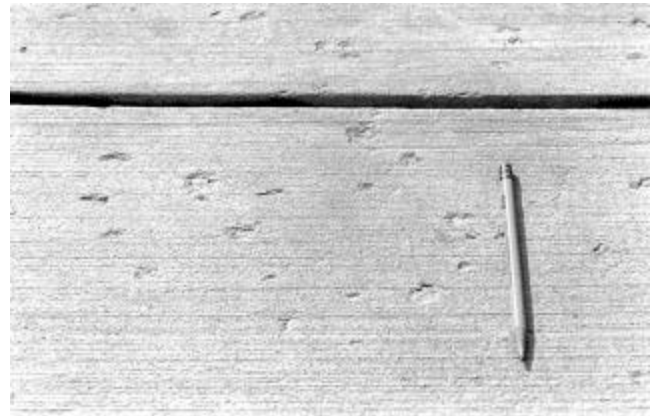

Fig. 11.5.1—Mortar flaking over coarse aggregate particles is another form of scaling that resembles a surface with popouts

Fig. 11.6—A popout is a small fragment of concrete broken away from the surface of a slab due to internal pressure, leaving a shallow, typically conical, depression

the expansion of a piece of chert, soft fine-grained limestone, shale, hard-burned lime, hard-burned dolomite, pyrite, or coal. The first two are natural constituents of some aggregates; the others sometimes find their way into aggregates as impurities. In some materials, the expansion is caused by freezing or absorption of moisture; in others it is caused by a chemical change. For example, popouts can occur from the chemical reaction between alkalies in concrete and reactive siliceous aggregates. Popouts range in size from about $1/4$ to 2 in. (6 to 50 mm) or more in diameter.

  \Because popouts usually do not significantly diminish the integrity of concrete flatwork, they are sometimes tolerated. Nevertheless, they are usually unsightly and interfere with the performance of any slab required to be smooth. On floors with hard-wheeled traffic, popouts can degenerate into larger imperfections. Early repair should minimize further problems in high-traffic areas.

  The occurrence of impurities in the concrete can be beyond the control of the floor constructor, since it usually occurs inadvertently in the production and handling of ready-mixed concrete or its constituents. The presence of naturally occurring chert or soft fine-grained limestone, however, can

be a continuing problem in some locales. Measures that can be taken to alleviate the problem are:

1. Switching to a nonoffending source of aggregate for floors and slabs, if possible.

2. Using two-course construction with selected or imported aggregate without popout potential for the topping course.

3. Using aggregates from which the offending particles have been removed by heavy-media separation, if available and economically feasible.

4. Using wet-curing methods such as continuous fogging, or covering with wet burlap immediately after final finishing. Wet-cure for a minimum of 7 days, since wet curing can greatly reduce or eliminate popouts caused by alkali-aggregate reactivity.[44] Avoid plastic film, curing paper, and especially curing compounds, since they allow an accumulation of alkalies at the surface. Impervious floor coverings or membranes, such as wax, epoxy, or other coatings, should be avoided because they can aggravate popout development.

5. Using the lowest *practical* slump possible to prevent potential popout-causing particles from floating to the surface.

In some areas and situations, these measures may not be practical. Specific local practices have been developed that have been helpful in minimizing popouts. For example, in some regions ready mix producers can supply popout-free concrete.

11.7—Blisters

The appearance of blisters (Fig. 11.7) on the surface of a concrete slab during finishing operations is annoying and an imperfection not easily repaired once the concrete hardens. These "bumps" can range in size from $^1/_4$ to 4 in. (6 to 100 mm) in diameter with a depth of about $^1/_8$ in. (3 mm). They appear when bubbles of entrapped air or water rise through the plastic concrete and are trapped under an already sealed, airtight surface. This early closing of the surface frequently happens when the top of a slab stiffens, dries, or sets faster than the underlying concrete. Experienced finishers attribute blistering to the following:

1. An excessive amount of entrapped or entrained air held within the concrete by excessive fines—material passing the Nos. 30, 50, and 100 sieves (600, 300, and 150 μm)—resulting in a sticky mixture that can become more easily sealed during the closing and troweling operations. Sticky mixtures have a tendency to crust under drying winds, while the remainder of

Fig. 11.7—Blisters

the concrete stays plastic. Usually, what is needed to relieve this condition is to reduce the amount of sand in the mix by 100 to 200 lb per cu yd (60 to 120 kg/m^3), and to replace the removed sand with a like amount of the smallest-size coarse aggregate available. The resulting slightly harsher mix should release most of the entrapped air using normal vibration. On days when surface crusting occurs, slightly modified finishing techniques may be needed, such as the use of wooden floats to keep the surface open, and flat troweling to avoid enfolding air into the surface under the blade action.

2. Insufficient vibration during compaction that does not adequately release entrapped air, or overuse of vibration that leaves the surface with excessive fines, inviting crusting and early finishing.

3. Finishing when the concrete is still spongy. Any tool used to compact or finish the surface will tend to force the entrapped air toward the surface. Blisters may not appear after the first finishing pass, but later, as the work progresses to the second or third troweling. At this stage in finishing, the trowel blade is tilted to increase surface density; air and water just under the surface are forced ahead of the blade until enough is concentrated (usually near a piece of large aggregate) to form a blister. Blisters, which can be full of air and/or water when punctured, also can appear at any time during finishing operations and without apparent cause. Floating the concrete a second time helps to reduce blistering. Delayed troweling will depress the blisters even though it may not reestablish complete bond.

To avoid blisters, the following should be considered:

1. Avoid the use of concrete with excessively high slump, water content, air content, or fines.

2. Use appropriate cement contents (Table 6.2.4).

3. Warm the base before placing concrete during cool weather. During hot, dry, windy weather, reduce evaporation over the slab by using an evaporation retardant (monomolecular film), a fog spray, or a slab cover (polyethylene film or wet burlap).

4. Avoid placing a slab directly on polyethylene film or any other vapor retarder. Use a minimum 4-in.-thick (100-mm) layer of trimmable, compactible granular fill *(not sand)* to separate the vapor retarder from the concrete (Section 4.1.5).

5. Avoid overworking the concrete, especially with vibrating screeds, jitterbugs, or bull floats. Overworking causes coarse aggregate to settle, and bleed water and excess fines to rise to the surface. Properly vibrate concrete to release entrapped air.

6. Do not use pans for initial machine floating.

7. Do not attempt to seal (finish) the surface too soon. Hand floating should be started when a worker standing on a slab makes a $^1/_4$-in. (6-mm) footprint; for machine floating, the footprint should be only about $^1/_8$ in. (3 mm) deep. If moisture is deficient, a magnesium float should be used.

8. Use a wooden bull float on non-air-entrained concrete to avoid early sealing. Magnesium or aluminum tools should be used on air-entrained concrete. Slabs that incorporate a surface hardener are more prone to blister if not properly finished (Sections 8.6.1 and 8.6.2).

9. Use proper finishing techniques and proper timing during and between finishing operations (Section 8.3). The formation of blisters is an immediate indication that the angle of the trowel is too great for the surface in that area at that particular time with the concrete and job conditions involved. The position of the trowel should be flattened, and the blistered area re-troweled immediately to eliminate and rebond the blisters. If frequent blistering occurs despite reasonable care in the timing and technique employed in the finished troweling, attention should be directed to the job and climatic conditions, and to the concrete mixture.

Most skilled finishers know when a concrete surface is ready for the raised and final troweling and closing of the surface, and how to accomplish this operation. However, circumstances are often beyond their control. For instance, if there are too few finishers for the climatic conditions, finishers may have to close some portions of a floor too early in order to get it troweled before it has set too much. Similarly, if supervisors insist that a floor be finished by a certain time, whether it is ready or not, blisters, trowel marks, and poor surfaces can result.

11.8—Spalling

Unlike scaling and blistering, spalling is a deeper surface imperfection, often extending to the top layers of reinforcing steel or to the horizontal joint between the base and topping in two-course construction. Spalls can be 6 in. (150 mm) or more in diameter and 1 in. (25 mm) or more in depth, although smaller spalls also occur. Spalls are caused by pressure or expansion within the concrete, bond failure in two-course construction, impact loads, fire, or weathering. Joint spalls are often caused by improperly constructed joints. Spalls can occur over corroding reinforcing steel because the corrosion products (rust) occupy more volume than the original steel, and the resultant pressure spalls the concrete.

In addition to its poor appearance, spalling can seriously impair the strength or serviceability of a floor or slab. Indoor spalling is more likely to result from improper joint design or installation or bond failure in two-course floor construction, but obviously this can happen outdoors as well. Causes for the various kinds of spalling include:

1. Insufficient depth of cover over reinforcement.

2. Inferior concrete in the cover over reinforcing steel. Such concrete can fail to protect the steel from disruptive corrosion because of its high permeability due to:

  a. Overworking overwet concrete during finishing (Sections 8.3.10 and 8.3.3).

  b. Serious loss of entrained air during such wet-finishing operations.

  c. Problems with excessive bleeding during finishing, especially in cold weather (Sections 8.16 and 8.17).

  d. Inadequate or delayed curing.

  e. Severe cracking that permits water and salts to attack the steel.

  f. Loss of bond between concrete and reinforcing steel bars, caused by placement of concrete on top of excessively hot steel during hot-weather concreting.

3. Joint edge spalls caused by small-hard-wheeled vehicles traveling across improperly installed or filled joints (Sections 3.2.6, 5.12, and 9.10), and spalls on the upper flange of the female side of keyed-construction joints.

4. Poor bonding of topping to base course in two-course floors (Sections 8.7.1 and 8.7.2) due to:

  a. Inferior quality of surface concrete in the base course.

  b. Unremoved contamination in, or poor preparation of, the surface of the base course.

  c. Differences in shrinkage between topping and base courses.

  d. Drying of the bonding grout before the topping concrete is placed.

  e. Excessive pressure developed at joints, where preformed joint material was topped by continuous concrete.

  f. Restraint of movement of deck slabs on supporting walls and piers due to inadequate provision for such movement.

11.9—Discoloration

Surface discoloration of concrete flatwork can appear as gross color changes in large areas of concrete, as spotted or mottled light or dark blotches on the surface, or as early light patches of efflorescence. Laboratory studies to determine the effects of various concrete materials and concreting procedures show that no single factor is responsible for discoloration.[46] Factors found to influence discoloration are calcium chloride admixtures, concrete alkalies, hard-troweled surfaces, inadequate or inappropriate curing, variations in water-cementitious material ratio at the surface, and changes in the concrete mixture. Like many other surface imperfections, discoloration is generally a cosmetic nuisance, rather than a structural or serviceability problem.

Dark areas do not necessarily denote inferior serviceability unless there is evidence that dry cement has been troweled into the surface to absorb excess bleed water (Section 8.16). The following are causes of dark areas:

1. The use of calcium chloride in concrete can discolor the surface (Fig. 11.9). Calcium chloride accelerates the overall hydration process, but has a retarding effect on the hydration of the ferrite compounds in portland cement. The ferrite
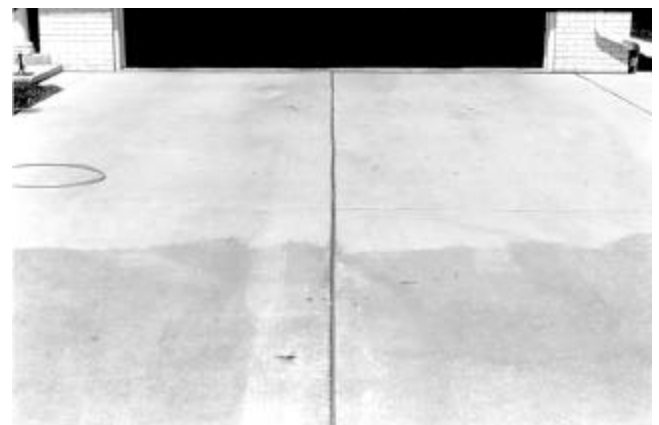

Fig. 11.9—Concrete slab discoloration due to the use of calcium chloride admixture. Concrete in the upper part of the photo did not contain the admixture

phases normally become lighter with hydration; however, in the presence of calcium chloride the retarded, unhydrated ferrite phases remain dark in color.

2. Low spots where water stands longer before evaporating.

3. Curing with waterproof paper and plastic sheets can cause a lighter color where the sheet is in contact with the surface, and a darker color where the sheet is not in contact with the surface. This type of discoloration is aggravated when concrete contains calcium chloride.

4. Changes in the water-cementitious material ratio of concrete mixtures can significantly affect color. Such a change can result from localized changes in construction practices, from a batch-to-batch variation in the concrete's water or cementitious material content, or from steel troweling. A high water-cementitious material ratio will usually produce a light-colored concrete, a low ratio a darker color. Repeated hard-steel troweling in areas of advanced setting reduces the water-cementitious material ratio at the surface, darkening its color.

5. Changes in source or type of cement. Individual brands and types of cement can differ in color; therefore, changing brand or type of cement in the middle of a job can noticeably change the color of concrete.

6. Uneven application of dry-shake materials, such as mineral-aggregate or metallic hardeners.

7. Changes in the amount, source, and chemistry of a mineral admixture. The extent of the discoloration will depend upon the color and the amount of admixture used. Some mineral admixtures resemble portland cement and have no effects on concrete color. Silica fume can give concrete a dark-gray tint. Dark-gray fly ashes can also give concrete a darker color, whereas tan- or beige-colored fly ashes, if used in large quantities, can produce a tan color in concrete.

Light-colored areas can simply be the result of contrast to adjacent dark areas; these would not normally impair serviceability. However, if light-colored areas are caused by local overworking of excessively wet concrete, the surface will be weaker and serviceability can be impaired. This can be caused by high concrete water content or finishing while there is excess moisture or bleed water on the surface.

Light-colored areas also can be caused by efflorescence (a crystalline deposit—usually white in color—that occasionally develops on the surface of concrete slabs after construction is completed). Moisture present in hardened concrete dissolves soluble salts. These salts in solution migrate to the surface by evaporation or hydraulic pressure where the water evaporates and leaves a deposit of salt at the surface. If the water, the evaporation, or the salts are not present, efflorescence will not occur.

11.10—Low spots and poor drainage

Puddles or "bird baths" on an outdoor concrete slab after a rain, or on a floor after hosing, characterize poor slab or floor surface drainage or serviceability. Among the primary causes:

1. Inadequate slope. Positive drainage requires a slope of $^1/_4$ in. per ft (20 mm/m) for an exterior slab; for an interior floor slab, $^1/_{16}$ in. per ft (5 mm/m) minimum is adequate for drainage, but $^1/_8$ in. per ft (10 mm/m) is preferred.

2. Inaccuracy in setting grades for forms and screeds.

3. Damage to grade settings of forms and screeds during construction.

4. Strikeoff operation in which low spots are filled in with extra-wet concrete. The wetter concrete settles more than the surrounding areas during the interval between strikeoff and floating operations.

5. Fresh concrete that is too wet or variably wet. A little working of such concrete results in areas with excessive mortar at the surface, which settles more than the surrounding areas.

6. Failure to frequently check grades, levels, and slopes with long straightedges (Sections 8.2.5 and 8.3.4), and to properly build up low spots in areas thus detected.

7. Tooling joint grooves without removing the small amount of mortar displaced. The ridge of mortar formed in this way can act as a dam.

8. Failure to check the finished grade following strikeoff when wet-screeds are used (Section 8.3.2).

9. Poor lighting during placing and finishing.

10. Deflection of suspended slabs between supports after removal of supporting shores.

11.11—Curling

Curling is the distortion (rising up) of a slab's corners and edges due to differences in moisture content or temperature between the top and bottom of a slab. The top dries out or cools, and contracts more than the wetter or warmer bottom. If the curled section of a slab is loaded beyond the flexural strength of the concrete, cracks will develop parallel to the joints at which curling occurs.

Slabs also can be dished in the center because the centers were finished lower than the screeds. This is readily apparent from straightedging after finishing. There are a number of ways to reduce slab curling:

1. Equalize moisture content and temperature between the top and bottom of a slab.

2. Use a concrete mixture with low-shrinkage characteristics, that is, a stony concrete mixture with large maximum-size coarse aggregate at the highest quantity consistent with the required workability. Such mixtures minimize water content.

3. Use a permeable (porous) dry—or almost dry—base.

4. Use shrinkage-compensating concrete.

5. Place a generous amount of reinforcement in the top third of the slab. One percent reinforcement could be justified in the direction perpendicular to the slab edge or construction joint, and for about 10 ft (3 m) in from the slab edge or construction joint.

6. Use post-tensioning.

Some of the measures that can reduce moisture differentials between the top and the bottom of a slab are:

1. Cure the slab well, particularly during early ages. Use of a continuous moist cure or a high-solids curing compound (Sections 5.9.3 and 9.2.4)—especially during the first few days—can greatly reduce the rate of water lost from the concrete and help reduce moisture differentials.

2. After proper curing, further reduce moisture loss from the top of slabs by using coatings, sealers, and waxes. These also reduce carbonation, which adds to surface shrinkage.

3. If a vapor retarder is necessary, use a minimum 4-in.-thick (100-mm) layer of trimable, compactible granular fill (*not sand*) between the vapor retarder and concrete slab (Section 4.1.5). Material conforming to ASTM D 448, No. 10, with plenty of rock fines, has been used successfully. If the fill is dry—or almost dry—this will permit some moisture loss from the slab bottom. The fill should be designed so that it does not retain water.

Measures to reduce the shrinkage potential of a concrete mixture include:

1. Reduce total water content of concrete by:
 a. Maintaining the proper slump (Table 6.2.1).
 b. Reducing the as-mixed temperature of the concrete.
 c. Avoiding delays in placement that require large quantities of retempering water.
 d. Selecting hard aggregates that are well graded for good workability at minimum water contents, and contain a minimum of fines. Aggregates should be generally rounded or cubical in shape, with a minimum of flat or elongated particles.
 e. Increasing the maximum size of coarse aggregate and using coarser sand.
 f. Reducing the sand content to the lowest level consistent with adequate workability and mixing water requirements.
 g. Using a high-range water-reducing admixture (superplasticizer) with good shrinkage-reduction history and tests.

2. Avoid aggregates known to have high-shrinkage potential, such as sandstone, slate, hornblende, and some types of basalt. Hard, rigid aggregates that are difficult to compress provide more restraint to shrinkage of cement paste in concrete than softer aggregates. Quartz, granite, feldspar, limestone, dolomite, and some basalt aggregates generally produce concretes with low drying shrinkage (ACI 224R).

3. Minimize aggregate gap-grading.

4. Avoid admixtures or concrete constituents that increase drying shrinkage.[33,44] Use of a water-reducing admixture—or other admixture conforming to ASTM C 494 and intended for reducing the water demand of concrete—will not necessarily decrease the drying shrinkage of concrete. Unless concretes contain very low levels of calcium chloride or triethanolamine, drying shrinkage generally will be increased. Chlorides can get into concrete from admixtures, water, aggregates, or cement.

5. Dewatering techniques (Section 8.3.6) of fresh concrete slab surfaces can significantly reduce water content, and thus help reduce slab curling. However, since vacuum mats do not extend fully to the edges of the forms and screeds, it is possible for the joints at the forms and screeds to end up slightly higher than the overall slab surface after vacuum dewatering is completed. Where wheeled traffic—especially automated guided vehicles—will be involved, this should be taken into consideration during screeding, leveling, and bull floating to the forms and screeds.

Placing concrete at lower temperatures can reduce thermal contraction from cooling. Curling magnitude can diminish with age as moisture and temperature equalize throughout the slab thickness. In addition, creep probably reduces curling over a period of months.

Concrete strength should be only as high as necessary for the floor or slab to fulfill its function (Tables 2.1 and 6.2.1). Excessively high strengths reduce creep and this can accentuate curling. However, high strength quality concrete slabs have less cracking due to higher early flexural and tensile strengths.

11.12—Analysis of surface imperfections

The cause of most surface imperfections can be determined by petrographic (microscopic) analysis on samples of the concrete. A petrographic analysis of concrete is performed in accordance with ASTM C 856.

Samples for the analysis are usually 4-in.-diameter (100-mm) drilled cores or saw-cut sections. Broken sections can be used, but cores or saw-cut sections are preferred because they are less apt to be disturbed. Samples should represent concrete from both the problem and the nonproblem areas. The petrographer should be provided with a description and photographs of the problem, in addition to information on the concrete mixture proportions, construction practices used, and environmental conditions. A field review by a petrographer, engineer, or concrete technologist is also helpful in analyzing the imperfection.

The petrographic report often includes the probable cause of the problem, extent of distress, the general quality of the concrete, and expected durability and performance of the concrete. Corrective action, if necessary, would be based to a great extent on the petrographic report.

CHAPTER 12—SELECTED REFERENCES

12.1—Specifications and recommended references

The documents of the various standards-producing organizations referred to in this Guide are listed below with their serial designation:

American Association of State Highway and Transportation Officials (AASHTO)

M 182 Standard Specification for Burlap Cloth Made from Jute or Kenaf

T 26 Standard Method of Test for Quality of Water to Be Used in Concrete

American Concrete Institute (ACI)

116R Cement and Concrete Terminology

117 Standard Specifications for Tolerances for Concrete Construction and Materials

201.2R Guide to Durable Concrete

211.1 Standard Practice for Selecting Proportions for Normal, Heavyweight and Mass Concrete

211.2 Standard Practice for Selecting Proportions for Structural Lightweight Concrete

211.3 Standard Practice for Selecting Proportions for No-Slump Concrete

212.3R Chemical Admixtures for Concrete

212.4R Guide for the Use of High-Range Water-Reducing Admixtures (Superplasticizers) in Concrete

222R Corrosion of Metals in Concrete

223 Standard Practice for the Use of Shrinkage-Compensating Concrete

224R Control of Cracking in Concrete Structures

224.1R Causes, Evaluation, and Repair of Cracks in Concrete Structures

224.3R Joints in Concrete Construction

226.1R Ground Granulated Blast-Furnace Slag as a Cementitious Constituent in Concrete

226.3R Use of Fly Ash in Concrete

301 Specifications for Structural Concrete for Buildings

304R Guide for Measuring, Mixing, Transporting, and Placing Concrete

305R Hot Weather Concreting

306R Cold Weather Concreting

308 Standard Practice for Curing Concrete

309R Guide for Consolidation of Concrete

311.1R ACI Manual of Concrete Inspection (SP-2)

311.4R Guide for Concrete Inspection

318 Building Code Requirements for Reinforced Concrete with Commentary

325.9R Recommendations for Construction of Concrete Pavements and Concrete Bases

330R Guide for Design and Construction of Concrete Parking Lots

332R Guide to Residential Cast-in-Place Concrete Construction

347R Guide to Formwork for Concrete

360R Design of Slabs on Grade

421.1R Shear Reinforcement for Slab

423.3R Recommendations for Concrete Members Prestressed with Unbonded Tendons

503R Use of Epoxy Compounds with Concrete

503.2 Standard Specifications for Bonding Plastic Concrete to Hardened Concrete with a Multi-Component Epoxy Adhesive

504R Guide to Sealing Joints in Concrete Structures

515.1R A Guide to the Use of Waterproofing, Dampproofing, Protective and Decorative Barrier Systems for Concrete

544.1R State-of-the-Art Report on Fiber Reinforced Concrete

544.2R Measurement of Properties of Fiber Reinforced Concrete

544.3R Guide for Specifying, Proportioning, Mixing, Placing, and Finishing Steel Fiber Reinforced Concrete

544.4R Design Considerations for Steel Fiber Reinforced Concrete

C-640 Craftsman Certification

American National Standards Institute (ANSI)

A122.1 Specifications for Vermiculite Concrete Roofs and Slabs on Grade

American Society of Civil Engineers (ASCE)

ANSI/ASCE 3 Standard for the Structural Design of Composite Slabs

ANSI/ASCE 9 Standard Practice for Construction and Inspection of Composite Slabs

American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE)

90.1 Energy Conservation in New Building Design (Sections 1 through 9)

American Society for Testing and Materials (ASTM)

A 36 Specification for Structural Steel

A 184 Specification for Fabricated Deformed Steel Bar Mats for Concrete Reinforcement

A 185 Specification for Steel Welded Wire Fabric, Plain, for Concrete Reinforcement

A 416 Specification for Steel Strand, Uncoated Seven-Wire for Prestressed Concrete

A 497 Specification for Steel Welded Wire Fabric, Deformed, for Concrete Reinforcement

A 615 Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement

A 616 Specification for Rail-Steel Deformed and Plain Bars for Concrete Reinforcement

A 617 Specification for Axle-Steel Deformed and Plain Bars for Concrete Reinforcement

A 820 Specification for Steel Fibers for Use in Fiber Reinforced Concrete

C 33 Specification for Concrete Aggregates

C 94 Specification for Ready-Mixed Concrete

C 109 Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or 50-mm Cube Specimens)

C 150 Specification for Portland Cement

C 156 Test Method for Water Retention by Concrete Curing Materials

C 157 Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete

C 171 Specification for Sheet Materials for Curing Concrete

C 227 Test Method for Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar-Bar Method)

C 260 Specification for Air-Entraining Admixtures for Concrete

C 295 Practice for Petrographic Examination of Aggregates for Concrete

C 309 Specification for Liquid Membrane-Forming Compounds for Curing Concrete

C 330 Specification for Lightweight Aggregates for Structural Concrete

C 387 Specification for Packaged, Dry, Combined Materials for Mortar and Concrete

C 494 Specification for Chemical Admixtures for Concrete

C 595 Specification for Blended Hydraulic Cements

C 618   Specification for Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete

C 685   Specification for Concrete Made by Volumetric Batching and Continuous Mixing

C 806   Test Method for Restrained Expansion of Expansive Cement Mortar

C 845   Specification for Expansive Hydraulic Cement

C 878   Test Method for Restrained Expansion of Shrinkage-Compensating Concrete

C 979   Specification for Pigments for Integrally Colored Concrete

C 989   Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars

C 1017   Specification for Chemical Admixtures for Use in Producing Flowing Concrete

C 1116   Specification for Fiber-Reinforced Concrete and Shotcret

C 1151   Test Method for Evaluating the Effectiveness of Materials for Curing Concrete

C 1157   Performance Specification for Blended Hydraulic Cement

D 448   Classification for Sizes of Aggregate for Road and Bridge Construction

D 994   Specification for Preformed Expansion Joint Filler for Concrete (Bituminous Type)

D 1751   Specification for Preformed Expansion Joint Filler for Concrete Paving and Structural Construction (Nonextruding and Resilient Bituminous Types)

D 1752   Specification for Preformed Sponge Rubber and Cork Expansion Joint Fillers for Concrete Paving and Structural Construction

D 2240   Test Method for Rubber Property—Durometer Hardness

E 96   Test Method for Water Vapor Transmission of Materials

E 1155   Test Method for Determining Floor Flatness and Levelness Using the F-Number System

The above publications may be obtained from the following organizations:

American Association of State Highway and Transportation Officials
333 West Capitol Street, NW, Suite 225
Washington, D.C 20001

American Concrete Institute
P.O. Box 9094
Farmington Hills, Mich. 48333-9094

American National Standards Institute
1430 Broadway
New York, N.Y. 10018

American Society of Civil Engineers
345 East 47th Street
New York, N.Y. 10017-2398

American Society of Heating, Refrigerating, and Air-Conditioning Engineers
1791 Tullie Circle, NE
Atlanta, Ga. 30329

American Society for Testing and Materials
100 Barr Harbor Dr.
West Conshohocken, Pa. 19428-2959

12.2—Cited references

1. Ytterberg, R. F., "Shrinkage and Curling of Slabs on Grade," *Concrete International: Design and Construction*, American Concrete Institute, Detroit, Apr. 1987, pp. 22-31; May 1987, pp. 54-61; and June 1987, pp. 72-81.

2. Campbell, Richard H., et al., "Job Conditions Affect Cracking and Strength of Concrete In Place," ACI JOURNAL, *Proceedings* V. 73, No. 1, Jan. 1976, pp. 10-13.

3. *Significance of Tests and Properties of Concrete and Concrete-Making Materials*, STP 169-C, American Society for Testing and Materials, Philadelphia, 1994, (Note especially Chapter 19, "Abrasion Resistance," pp. 182-191.)

4. Spears, Ralph, and Panarese, William C., *Concrete Floors on Ground*, EB075D, Portland Cement Association, Skokie, 2nd Edition, 1983, revised 1992.

5. Gustaferro, Armand H., "Are Thickness Tolerances for Concrete Floors on Grade Realistic?," *Concrete Construction*, Apr. 1989, pp. 389-391.

6. Anderson, T., and Roper, H., "Influence of an Impervious Membrane Beneath Concrete Slabs on Grade," *Symposium, Concrete for Engineering*, Institute of Engineers, Brisbane, Australia, Aug. 1977, pp. 51-56.

7. Nicholson, Leo P., "How to Minimize Cracking and Increase Strength of Slabs on Grade," *Concrete Construction*, Sept. 1981, pp. 739-742.

8. Turenne, R. G., "The Use of Vapor Barriers under Concrete Slabs on Ground," Building Practice *Note* No. 8, Division of Building Research, National Research Council of Canada, August 1978, 3 pp.

9. Dakhil, Fadh H.; Cady, Philip D.; and Carrier, Roger E., "Cracking of Fresh Concrete as Related to Reinforcement," ACI JOURNAL, *Proceedings* V. 72, No. 8, Aug. 1975, pp. 421-428.

10. *Manual of Standard Practice*, MSP-1-90, 25th Edition, Concrete Reinforcing Steel Institute, Schaumburg, 1990.

11. "Reinforcing Steel in Slabs-on-Grade," WRI/CRSI Engineering Data *Report* #37, Concrete Reinforcing Steel Institute, Schaumburg, 1991.

12. *Design and Construction of Post-Tensioned Slabs on Ground*, Post-Tensioning Institute, Phoenix, 1980.

13. *Post-Tensioning Manual*, 3rd Edition, Post-Tensioning Institute, Phoenix, 1981.

14. Schrader, Ernest K., "A Proposed Solution to Cracking by Dowels," *Concrete Construction*, Dec. 1987, pp. 1051-1053.

15. Colley, B. E., and Humphrey, H. A., *Aggregate Interlock at Joints in Concrete Pavements*, Development Department *Bulletin* DX124, Portland Cement Association, Skokie, 1967.

16. "Specifications for Unbonded Single Strand Tendons," *PCI Journal*, V. 30, No. 2, Post-Tensioning Institute, Phoenix, Mar./Apr. 1993.

17. Tipping, Eldon, "Building Superior Quality Elevated Floors," *Concrete Construction*, Apr. 1992, pp. 285-288.

18. "Panel Heating," *Heating, Ventilating, Air-Conditioning Guide*, V. 36, American Society of Heating and Ventilating Engineers, Atlanta, 1955, pp. 605-644.

19. Ringo, Boyd, "Basics of Subgrade Preparation for Industrial Floors," *Concrete Construction*, Feb. 1958, pp. 137-140.

20. "Precast Leave-in-Place Screed Rails for Floor Construction," *Concrete Construction*, May 1984, pp. 483-486.

21. Kauer, J. A., and Freeman, R. L., "Effects of Carbon Dioxide on Fresh Concrete," ACI JOURNAL, *Proceedings* V. 52, No. 4, Dec. 1955, pp. 447-454.

22. Bimel, Carl, "ASTM Specifications are a Start, But...," *Concrete International*, Dec. 1993, pp. 55.

23. Shilstone, James M., Sr., "Concrete Mixture Optimization," *Concrete International*, June 1990, pp. 33-39.

24. Boone, T. H., et al., "Conductive Flooring for Hospital Operating Rooms," *Journal of Research*, V. 630, No. 2, U.S. Department of Com-

merce, National Bureau of Standards, Washington, D.C., Oct.-Dec. 1958, pp. 125-140.

25. *Metallic Type Conductive and Spark-Resistant Concrete Floor Finish*, Guide Specification No. NFGS-09785, Naval Facilities Engineering Command, Apr. 1984, 14 pp.

26. Steinour, Harold H., "Concrete Mix Water—How Impure Can It Be?," Research Department *Bulletin* RX119, Portland Cement Association, Skokie, Sept. 1960.

27. Kosmatka, Steven H., and Panarese, William C., Chapter 3, "Mixing Water for Concrete," *Design and Control of Concrete Mixtures*, EB001T, 13th Edition, Portland Cement Association, Skokie, 1988, Revised 1994, pp. 26-29.

28. Martin, Ross, and Phelan, William S., "How Do Admixtures Influence Shrinkage?," *Concrete Construction*, July 1995, pp. 611-617.

29. ACI Committee 226, "Silica Fume in Concrete," *ACI Materials Journal*, American Concrete Institute, Detroit, Mar.-Apr. 1987.

30. "The Effect of Various Surface Treatments Using Magnesium and Zinc Fluosilicate Crystals on Abrasion Resistance of Concrete Surfaces," Concrete Laboratory *Report* No. C-819, U.S. Bureau of Reclamation, Denver.

31. Tatnall, P. C., and Kuitenbrouwer, L., "Steel Fiber Reinforced Concrete in Industrial Floors," *Concrete International*, Dec. 1992, pp. 43-47.

32. Balaguru, P. N., and Shah, S. P., *Fiber Reinforced Cement Composites*, McGraw-Hill, New York, 1992, 530 pp.

33. Tremper, Bailey, and Spellman, D. C., "Shrinkage of Concrete—Comparison of Laboratory and Field Performance," *Highway Research Record*, No. 3, Highway Research Board, Washington, D.C., 1963, pp. 30-61.

34. Kosmatka, Steven H., and Panarese, William C, Chapter 7, "Proportioning Normal Concrete Mixtures," *Design and Control of Concrete Mixtures*, EB001T, 13th Edition, Portland Cement Association, Skokie, 1988, Revised 1994, pp. 77-93.

35. Martin, Ross, "Discussion, Proposed Revisions to Specifications for Structural Concrete for Buildings (ACI 301-72) (Rev. 1981)," ACI JOURNAL, *Proceedings* V. 80, No. 6, Nov.-Dec. 1983, p. 548.

36. Wenander, Harold, "Vacuum Dewatering Is Back," *Concrete Construction*, V. 20, No. 2, Feb.1975, pp. 40-42.

37. Wenander, Harold; Danielsson, Jan. L.; and Sendker, F. T., "Floor Construction by Vacuum Dewatering," *Concrete Construction*, V. 20, No. 2, Feb. 1975, pp. 43-46.

38. Malinowski, Roman, and Wenander, Harold, "Factors Determining Characteristics and Composition of Vacuum-Dewatered Concrete," ACI JOURNAL, *Proceedings* V. 72, No. 3, Mar. 1975, pp. 98-101.

39. "Floor Finishing," *Lightweight Concrete Information Sheet* No. 7, Expanded Shale, Clay and Slate Institute, Bethesda, 1958, 4 pp.

40. Brungraber, Robert J., "New Portable Tester for the Evaluation of the Slip-Resistance of Walkway Surfaces," *NBS Technical Note* No. 953, U.S. Department of Commerce, National Bureau of Standards, Washington, D.C., July 1977, 43 pp.

41. Brungraber, Robert J., "Overview of Floor Slip-Resistance Research with Annotated Bibliography," *NBS Technical Note* No. 895, U.S. Department of Commerce, National Bureau of Standards, Washington, D.C., Jan. 1976, 108 pp.

42. Kosmatka, Steven H., *Finishing Concrete Slabs With Color and Texture*, PA124H, Portland Cement Association, Skokie, 1991, 40 pp.

43. Face, Allen, "Floor Flatness and Levelness—The F-Number System," *Construction Specifier*, V. 40, No. 4, Apr. 1987, pp. 24-32.

44. Whiting, D., and Dziedzic, W., "Effects of Conventional and High-Range Water Reducers on Concrete Properties," Research and Development *Bulletin* RD107T, Portland Cement Association, Skokie, 1992.

45. "Popouts: Causes, Prevention, Repair," *PCA's Concrete Technology Today*, June 1995.

46. Greening, N. R., and Landgren, R., "Surface Discoloration of Concrete Flatwork," Research Department *Bulletin* RX203, Portland Cement Association, Skokie, 1966.

12.3—Additional references

Chapter 1

"Concrete Specifications: Read and Write Them Carefully," *Concrete Technology Today*, PL941B, Portland Cement Association, Skokie, Mar. 1994.

Hoff, Philip L., "Industrial Floors—Before You Build," *Concrete Technology Today*, PL863B, Portland Cement Association, Skokie, Sept. 1986.

Chapter 2

Gray, J. E., *Report on Skid Resistance of Portland Cement Mortar Surfaces*, Projects 61-34-36-36, National Crushed Stone Association, Washington, D.C., Mar. 1962, 22 pp.

Chapter 3

"Concrete Myths: Vapor Barriers are Always Required under Slab-on-Grade Floors," *Concrete Technology Today*, PL823B, Portland Cement Association, Skokie, Sept. 1982.

Garber, George, "Post-Tensioning for Crack-Free Superflat Floors," *Concrete Construction*, May 1983, pp. 396-400.

"Load Transfer Across Joints in Floors," *Concrete Technology Today*, PL814B, Portland Cement Association, Skokie, Dec. 1981.

Nussbaum, Peter J., "Reflections on Reinforcing Steel in Slabs on Grade," *Concrete Technology Today*, PL922B, Portland Cement Association, Skokie, July 1992.

Packard, Robert G., "Slab Thickness Design for Industrial Concrete Floors on Grade," *Concrete Information*, IS195D, Portland Cement Association, Skokie, 1976, 16 pp.

"Reinforcing Steel in Slabs on Grade," *Concrete Technology Today*, PL921B, Portland Cement Association, Skokie, Mar. 1992.

Ringo, Boyd, "Effect of Design Variables on Floor Thickness Requirements," *Concrete Construction*, Jan. 1992, pp. 13-14.

Ringo, Boyd C., and Anderson, Robert B., "Choosing Design Methods for Industrial Floor Slabs," *Concrete Construction*, Apr. 1994, pp. 346-352.

Suprenant, Bruce, "Construction of Elevated Concrete Slabs—Understanding the Effect of Structural Systems," *Concrete Construction*, V. 35, No. 11, Nov. 1990, pp. 910-917.

Tipping, Eldon, and Suprenant, Bruce, "Construction of Elevated Concrete Slabs—Practice and Procedures," *Concrete Construction*, V. 36, No. 1, Jan. 1991, pp. 32-42.

Tipping, Eldon, and Suprenant, Bruce, "Construction of Elevated Concrete Slabs—Measuring and Evaluating Quality," *Concrete Construction*, V. 36, No. 3, Mar. 1991, pp. 260-268.

Tipping, Eldon, "Tolerance Conflicts and Omissions in Suspended Slab Construction," *Concrete International: Design & Construction*, V. 14, No. 8, Aug. 1992, pp. 33-37.

Tipping, Eldon, "Controlling the Quality of Suspended Slab Construction," *Concrete International: Design & Construction*, V. 14, No. 8, Aug. 1992, pp. 38-40.

Tobin, Robert E., "How to Double the Value of Your Concrete Dollar," *Concrete Technology Today*, PL852B, Portland Cement Association, Skokie, June 1985.

Chapter 4

Anderson, Robert B., "Soil Information Needed for Slab Design," *Concrete Construction*, Apr. 1992, pp. 289-290.

ACI Committee 332, "Guide for Construction of Concrete Floors on Grade," ACI JOURNAL, *Proceedings* V. 59, No. 10, Oct. 1962, pp. 1377-1390.

"Concrete Screed Rails Used for Concrete Placed on Metal Decks," *Concrete Construction*, Apr. 1991, pp. 341-342.

Fitzpatrick, Robert, "Designing Durable Industrial Floor Slabs," *Concrete International*, Jan. 1996, pp. 38-39.

Schmidt, Norbert O., and Riggs, Charles O., "Methods for Achieving and Measuring Soil Compaction," *Concrete Construction*, Aug. 1985, pp. 681-689.

"Subgrades and Subbases for Concrete Pavements," *Concrete Information*, IS029P, Portland Cement Association, Skokie, 1991, 24 pp.

Chapter 5

Bimel, Carl, "Trap Rock Aggregates for Floor Construction," *Concrete Construction*, Oct. 1988, pp. 946 and 948.

"Concrete Sealers for Protection of Bridge Structures," NCHRP *Report* No. 244, Transportation Research Board, Washington, D.C., 1981, 138 pp.

"A Contractor's Guide to Air-Entraining and Chemical Admixtures," *Concrete Construction*, Mar. 1990, pp. 279-286.

"Fly Ash in Concrete," *Concrete Construction*, May 1982, pp. 417-427.

"Fly Ash—Its Effect on Concrete Performance," *Concrete Technology Today*, PL833B, Portland Cement Association, Skokie, Sept. 1983.

Goeb, Eugene O., "Do Plastic Fibers Replace Wire Mesh in a Slab on Grade?," *Concrete Technology Today*, PL891B, Portland Cement Association, Skokie, Apr. 1989.

Gulyas, Robert J., "Dry Shake for Floors," *Concrete Construction*, Mar. 1984, pp. 285-289.

Kosmatka, Steven H., "Floor Covering Materials and Moisture in Concrete," *Concrete Technology Today*, PL853B, Portland Cement Association, Skokie, Sept. 1985.

Moens, J., and Nemegeer, D., "Designing Fiber Reinforced Concrete Based on Toughness Characteristics," *Concrete International*, Nov. 1991, pp. 38-43.

"Polymeric Fiber Reinforced Concrete," *Concrete Technology Today*, PL893B, Portland Cement Association, Skokie, Nov. 1989.

Robinson, Chuck; Colasanti, Angelo; and Boyd, Gary, "Steel Fibers Reinforce Auto Assembly Plant Floor," *Concrete International*, Apr. 1991, pp. 30-35.

Rocole, Larry, "Silica-Fume Concrete Proves to Be an Economical Alternative," *Concrete Construction*, June 1993, pp. 441-442.

Symposium on Use of Pozzolanic Materials in Mortars and Concretes, STP-99, American Society for Testing and Materials, Philadelphia, Aug. 1950, 203 pp.

"Working with Steel Fiber Reinforced Concrete," *Concrete Construction*, Jan. 1985, pp. 5-11.

Zollo, Ronald F., and Hays, Carol D., "Fibers vs. WWF as Non-Structural Slab Reinforcement," *Concrete International*, Nov. 1991, pp. 50-55.

Chapter 6

Kosmatka, Steven H., "ACI 318-89 and Deicer Exposure," *Concrete Technology Today*, PL903B, Portland Cement Association, Skokie, Sept. 1990.

Rose, Jerry G., "Yield of Concrete," *Concrete Construction*, Mar. 1986, pp. 313-316.

Shilstone, James M., "Concrete Strength Loss and Slump Loss in Summer," *Concrete Construction*, May 1982, pp. 429-432.

Chapter 7

"Control of Quality of Ready-Mixed Concrete," *Publication* No. 44, 5th Edition, National Ready Mixed Concrete Association, Silver Spring, Oct. 1962, 51 pp.

Hover, Ken, "Investigating Effects of Concrete Handling on Air Content," *Concrete Construction*, Sept. 1995, pp. 745-750.

Suprenant, Bruce A., "Adjusting Sump in the Field," *Concrete Construction*, Jan. 1994, pp. 38-44.

Chapter 8

Concrete Manual, 8th Edition, U.S. Bureau of Reclamation, Denver, 1975, pp. 457-467.

"Early Sawing to Control Slab Cracking," *Concrete Technology Today*, PL 953B, Portland Cement Association, Skokie, Nov. 1995.

"Finishing $$Ahead with Surface Vibration," *Concrete Technology Today*, PL822B, Portland Cement Association, Skokie, June 1982.

Fling, Russell S., "A Screeding Machine That's More Than a Strike-Off," *Concrete Construction*, Apr. 1987, pp. 351-353.

Fricks, Terry J., "Misunderstandings and Abuses in Flatwork Specifications," *Concrete Construction*, June 1994, pp. 492-497.

Hester, Weston T., "Superplasticizers in Ready Mixed Concrete (A Practical Treatment of Everyday Operations)," NRMC *Publication* No. 158, National Ready Mixed Concrete Association, Silver Spring, Jan. 1979.

Kosmatka, Steven H., "Repair with Thin-Bonded Overlay," *Concrete Technology Today*, PL 851B, Portland Cement Association, Skokie, Mar. 1985.

Lien, Rob, "Pan Floats Help Make Nestlè's Floors Sweet," *Concrete Construction*, May 1995, pp. 439-444.

Panarese, William C., *Cement Mason's Guide,* PA 122H, 6th Edition, Portland Cement Association, Skokie, 1995, 20 pp.

Phelan, William C., "Floors that Pass the Test," *Concrete Construction*, Jan. 1989, pp. 5-11.

Reed, Ray, and Schmidt, Greg, "Long-Strip Concrete Placement," *Concrete Construction,* Jan. 1994, pp. 46-50.

Suprenant, Bruce A., "Finishing Non-Bleeding Concrete," *Concrete Construction*, May 1992, pp. 386-389.

Tipping, Eldon, "Bidding and Building to F-Number Floor Specs," *Concrete Construction*, May 1992, pp. 18-19.

Tipping, Eldon, "Using the F-Number System to Manage Floor Installations (Part 1 of a 2-Part Series)," *Concrete Construction,* V. 41, No. 1, Jan. 1996, pp. 28-34.

Ytterberg, C. Fred, "Good Industrial Floors: What It Takes to Get Them and Why. Part 1: Monolithic Floors; Part 2: Concrete Toppings," *Civil Engineering,* V. 31, No. 2, Feb. 1961, pp. 55-58, and No. 4, Apr. 1961, pp. 60-63.

Chapter 9

Kosmatka, Steven H., and Panarese, William C., Chapter 10, "Curing," Chapter 11, "Hot-Weather Concreting," and Chapter 12, "Cold-Weather Concreting," *Design and Control of Concrete Mixtures*, EB001T, 13th Edition, Portland Cement Association, Skokie, 1988, Revised 1994, pp. 123-129, 130-136, and 137-150.

Metzger, Steven N., "Better Industrial Floors through Better Joints," *Concrete Construction*, Aug. 1988, pp. 749-754.

Metzger, Steven N., "Repairing Joints in Industrial Floors," *Concrete Construction*, June 1989, pp. 548-551

"Proper Curing—Preventive Medicine for Concrete," *Concrete Technology Today*, PL 823B, Portland Cement Association, Skokie, Sept. 1982.

Chapter 10

Hays, Raymond C., "Achieving Quality in Concrete Construction," *Concrete International*, Nov. 1995, pp. S-2 - S-3.

Shilstone, James M., "Quality Assurance and Quality Control," *Concrete Construction*, Nov. 1983, pp. 813-816.

Chapter 11

Bimel, Carl, "Concrete Contractors Do Not Create All Cracks," *Concrete International*, Jan. 1993.

Concrete Slab Surface Defects: Causes, Prevention, Repair, IS 177T, Portland Cement Association, Skokie, 1987.

Concrete Slabs on Grade: Design, Specification, Construction, and Problem Solving, SCM-25(92), American Concrete Institute, Detroit, 1992, 429 pp.

Kosmatka, Steven, H., "Petrographic Analysis of Concrete," *Concrete Technology Today*, PL 862B, Portland Cement Association, Skokie, July 1986.

"Slab Curling Is Not a Game Played on Ice," *Concrete Technology Today*, PL822B, Portland Cement Association, Skokie, June 1982.

ADDENDUM
GUIDE FOR CONCRETE FLOOR AND SLAB CONSTRUCTION
(302.1R-96)
Vapor Retarder Location

The report of ACI Committee 302, "Guide for Concrete Floor and Slab Construction (ACI 302.1R-96)" states in section 4.1.5 that "if a vapor barrier or retarder is required due to local conditions, these products should be placed under a minimum of 4 in. (100 mm) of trimable, compactible, granular fill (not sand)." ACI Committee 302 on Construction of Concrete Floors, and Committee 360 on Design of Slabs on Ground have found examples where this approach may have contributed to floor covering problems.

Based on the review of the details of problem installations, it became clear that the fill course above the vapor retarder can take on water from rain, wet-curing, wet-grinding or cutting, and cleaning. Unable to drain, the wet or saturated fill provides an additional source of water that contributes to moisture-vapor emission rates from the slab well in excess of the 3 to 5 lb/1000 ft^2/24 h (1.46 to 2.44 kg/100 m^2/24 h) recommendation of the floor covering manufacturers.

As a result of these experiences, and the difficulty in adequately protecting the fill course from water during the construction process, caution is advised on the use of the granular fill layer when moisture-sensitive finishes are to be applied to the slab surface.
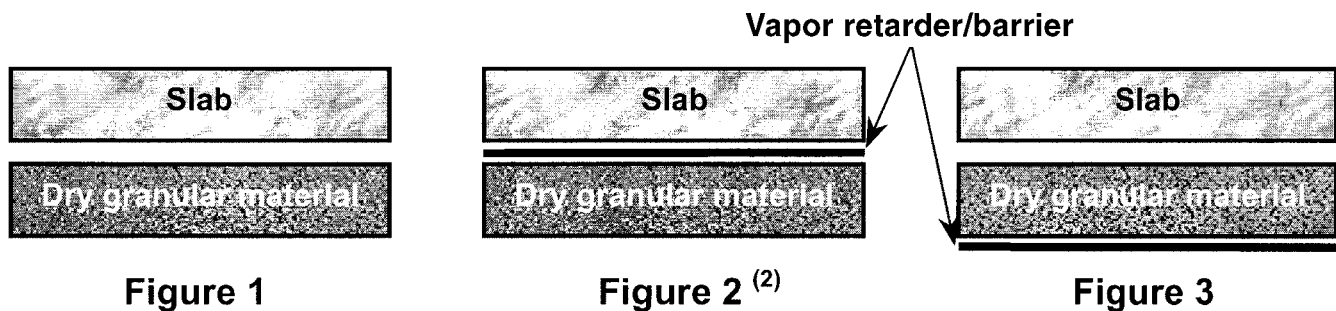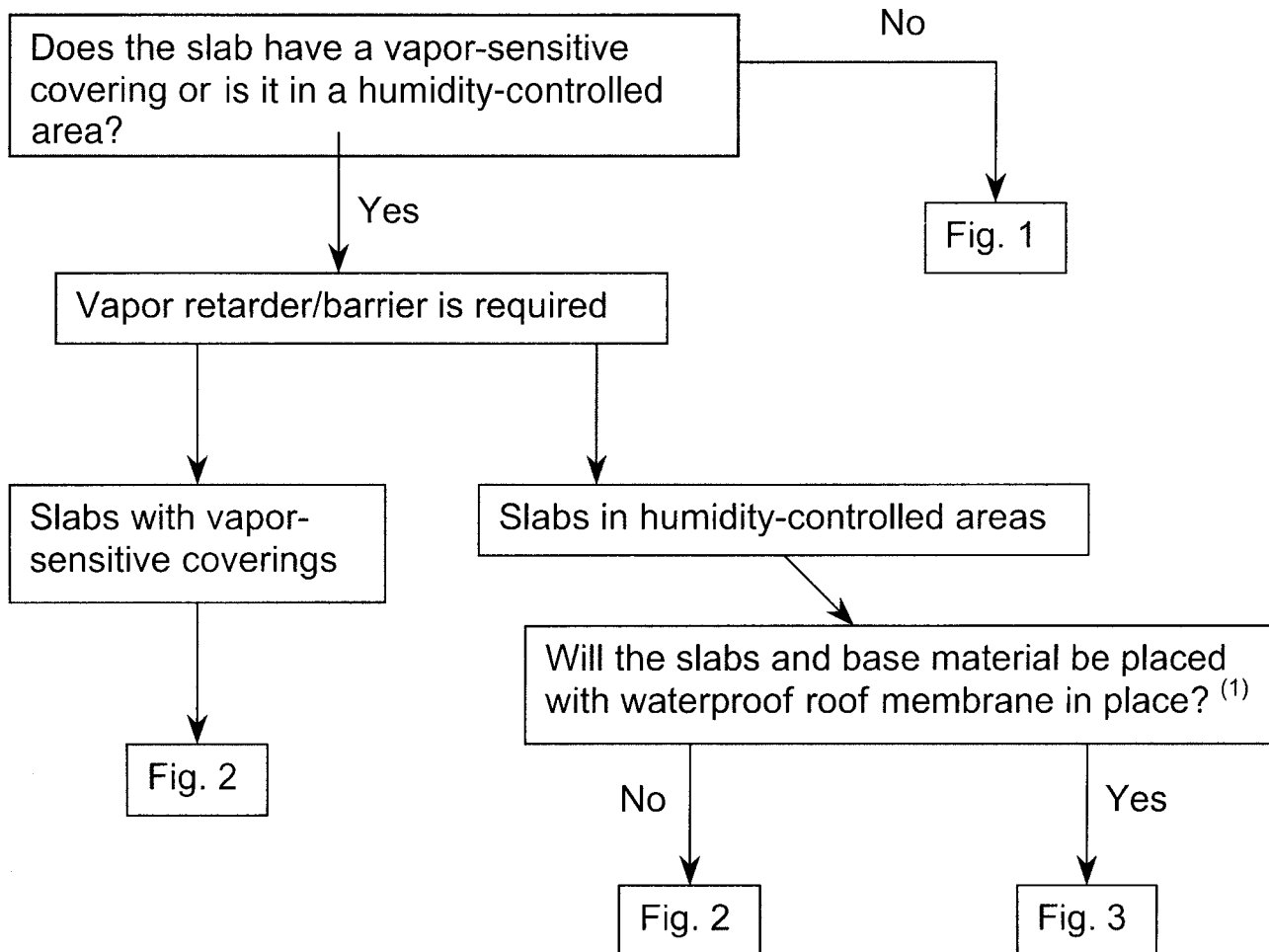
The committees believe that when the use of a vapor retarder or barrier is required, the decision whether to locate the retarder or barrier in direct contact with the slab or beneath a layer of granular fill should be made on a case-by-case basis.

Each proposed installation should be independently evaluated by considering the moisture sensitivity of subsequent floor finishes, anticipated project conditions and the potential effects of slab curling and cracking.

The following chart can be used to assist in deciding where to place the vapor retarder. The anticipated benefits and risks associated with the specified location of the vapor retarder should be reviewed with all appropriate parties before construction.

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(302.1R-96)
Flow Chart for Location of Vapor Retarder/Barrier

Does the slab have a vapor-sensitive covering or is it in a humidity-controlled area?

No → Fig. 1

Yes ↓

Vapor retarder/barrier is required

Slabs with vapor-sensitive coverings → Fig. 2

Slabs in humidity-controlled areas

Will the slabs and base material be placed with waterproof roof membrane in place? [1]

No → Fig. 2

Yes → Fig. 3

Vapor retarder/barrier

| Slab | Slab | Slab |
| Dry granular material | Dry granular material | Dry granular material |

Figure 1   **Figure 2** [2]   **Figure 3**

(1) If granular material is subject to future moisture infiltration, use Fig. 2

(2) If Fig. 2 is used, reduced joint spacing, a concrete with low shrinkage potential, or other measures to minimize slab curling will likely be required.