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ACI 302.1R-15

Guide to Concrete Floor and Slab Construction

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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, jointing, and curing—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, poor drainage, and 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, heat, or both, is being released to the surroundings. Moreover, because the drying and cooling rates at the top and bottom of the slab are not the same, the shrinkage will vary throughout the depth, causing the as-cast shape to be distorted and 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 elimination. Even with the best floor designs and proper construction, it is unrealistic to expect completely crack- and curl-free floors. 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 an occurrence does not necessarily reflect adversely on either the adequacy of the floor's design or the quality of its construction (Ytterberg 1987).

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, concrete materials, concrete mixture proportions, concrete workmanship, joint construction, load transfer across joints, form stripping procedures, finishing methods, and curing. 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 to achieve the floor qualities required by the project specifications. Adequate supervision and inspection are required for job operations, particularly those of finishing.

Keywords: admixture; aggregate; consolidation; contract documents; curing; curling; deflection; durability; form; fracture; joint; mixture proportioning; placing; quality control; slab-on-ground; slabs; slump test.

CONTENTS

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CHAPTER 1—INTRODUCTION

1.1—Purpose

This guide presents 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 normalweight and structural lightweight concrete floors and slabs made with conventional portland and blended cements. This guide identifies the various classes of floors based on use, construction design details, necessary site preparation, concrete type, and other related materials. In general, characteristics of the concrete slab surface and joint performance have a powerful impact on the serviceability of floors and other slabs. Because the eventual success of a concrete floor installation depends on 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.

1.2—Scope

This guide emphasizes choosing and proportioning of materials, design details, proper construction methods, and workmanship. Slabs specifically intended for the containment of liquids are beyond the scope of this guide. Whereas this guide does provide a reasonable overview of concrete floor construction, each project is unique and circumstances can dictate departures from the recommendations given in this guide. Contractors and suppliers should, therefore, thoroughly review contract documents before bid preparation (Chapter 3).

CHAPTER 2—DEFINITIONS

ACI provides a comprehensive list of definitions through an online resource, "ACI Concrete Terminology," http://www.concrete.org/store/productdetail.aspx?ItemID=CT13. Definitions provided herein complement that resource.

differential set time—difference in timing from initial introduction of water to concrete mixture at batch plant to initial power floating.

dry-shake—dry mixture of hydraulic cement and fine aggregate (either mineral or metallic) that is distributed evenly over the surface of concrete flatwork and worked into the surface before time of final setting and then floated and troweled to desired finish.

mixture optimization indicator—intersection of the coarseness factor value and the workability factor on the coarseness factor chart.

rutting—creation of troughs in the soil support system in response to applied wheel loads.

score—creation of lines or notches in the surface of a concrete slab.

soil pumping—vertical displacement and rebound of the soil support system in response to applied moving loads.

water slump—magnitude of slump, measured in accordance with ASTM C143/C143M, which is directly attributed to the amount of water in the concrete mixture.

window of finishability—time period available for finishing operations after the concrete has been placed, consolidated, and struck-off, and before final troweling.

workability factor—percentage of combined aggregate that passes the No. 8 (2.36 mm) sieve.

CHAPTER 5—DESIGN CONSIDERATIONS

5.1—Scope

Chapter 5 addresses the design of concrete floors as it relates to their constructibility. Specific design requirements for concrete floor construction are found in ACI 360R for slabs-on-ground, ACI 223R for shrinkage-compensating concrete floors, and ACI 421.1R and 421.2R for suspended floors.

5.2—Slabs-on-ground

5.2.1 *Required design elements*—Following are the minimum items that should be addressed in the construction documents prepared by the designer (ACI 360R):

a) Slab-on-ground design criteria

b) Base and subbase materials, preparation requirements, and vapor retarder/barrier, when required

c) Concrete thickness

d) Concrete compressive strength, flexural strength, or both

e) Concrete mixture proportion requirements, ultimate drying shrinkage strain, or both

f) Joint locations and details

g) Reinforcement (type, size, and location) when required

h) Surface treatment, when required

i) Surface finish

j) Tolerances (base, subbase, slab thickness, and floor flatness and levelness)

k) Concrete curing

l) Joint filling material and installation

m) Special embedments

n) Testing requirements

o) Preconstruction meeting, quality assurance, and quality control

If any of this information is not provided, the contractor should request it from the slab-on-ground slab designer.

5.2.2 *Soil-support system*—Because the performance of a slab-on-ground depends on the integrity of the soil-support system, specific attention should be given to site preparation requirements, including proof-rolling (6.1.1). In most cases, proof-rolling results are much more indicative of the soil-support system's ability to withstand loading than from the results of 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 concrete's thickness and to minimize friction between the base material and slab. For detailed information on soil-support systems, refer to ACI 360R.

5.2.3 *Moisture protection*—Proper moisture protection is essential for any slab-on-ground where the floor will be covered by moisture-sensitive flooring materials such as vinyl; linoleum; wood; carpet; rubber; rubber-backed carpet tile; impermeable floor coatings; adhesives; or where moisture-sensitive equipment, products, or environments exist, such as humidity-controlled or refrigerated rooms.

ACI 302.2R provides recommendations for the design and construction of concrete slabs that will receive moisture-sensitive or pH-sensitive flooring materials or coatings for both slabs-on-ground and suspended slabs.

5.2.3.1 *Vapor retarder permeance*—A vapor retarder/barrier is a material that is intended to minimize the transmission of water vapor upward through the slab from sources below. The performance requirements for plastic vapor retarder/barrier materials in contact with soil or granular fill under concrete slabs are listed in ASTM E1745. According to ASTM E1745 a vapor retarder/barrier material is to have a permeance level, also known as the water vapor transmission rate, not exceeding 0.1 perms as determined by ASTM E96/E96M or ASTM F1249. However, most flooring installations will benefit by using a material with a permeance level well below 0.1 perms (0.0659 metric perms = 5.72 $ng/s^{-1}m^{-2}Pa^{-1}$).

The selection of a vapor retarder/barrier material and its level of permeance should be made on the basis of the protective requirements of the material being applied to the floor surface or the environment being protected. Although conventional 6, 8, and 10 mil (0.15, 0.20, and 0.25 mm) polyethylene has been used in the past, this class of material does not fully conform to the requirements of ASTM E1745 and should not be considered for use as below-slab moisture protection. Any plastic vapor retarder/barrier material to be used below slabs should be in full compliance with the minimum requirements of ASTM E1745 and the thickness and permeance of the material be selected on the basis of protective needs and durability during and after installation.

However, for a material to be considered a true barrier it would need to have a permeance level of 0.0 perms when tested in accordance with ASTM E96/E96M or ASTM F1249. The industry has not established a permeance level that serves as the dividing point between materials classed as vapor barriers or vapor retarders. It is most likely that when a dividing point between barrier and retarder is established it will be at 0.01 perms or less. The laps or seams for a vapor retarder/barrier should be overlapped 6 in. (150 mm) (ASTM E1643) or as instructed by the manufacturer. Joints and penetrations should be sealed with the manufacturer's recommended adhesive, pressure-sensitive tape, or both.

5.2.3.2 *Vapor retarder/barrier location*—The decision to locate the vapor retarder/barrier in direct contact with the slab's underside had long been debated. Experience has shown, however, that the greatest level of protection for floor coverings, coatings, or building environments is provided when the vapor retarder/barrier is placed in direct contact with the slab. Placing concrete in direct contact with the vapor retarder/barrier eliminates the potential for water from sources such as rain, saw-cutting, curing, cleaning, or compaction to become trapped within the fill course. Wet or saturated fill above the vapor retarder/barrier can significantly lengthen the time required for a slab to dry to a level acceptable to the manufacturers of floor coverings, adhesives, and coatings. A fill layer sandwiched between the vapor retarder/barrier and the concrete also serves as an avenue for moisture to enter and travel freely beneath the slab, which can lead to an increase in moisture within the slab once it is covered. Moisture can enter the fill layer through voids, tears, or punctures in the vapor retarder/barrier.

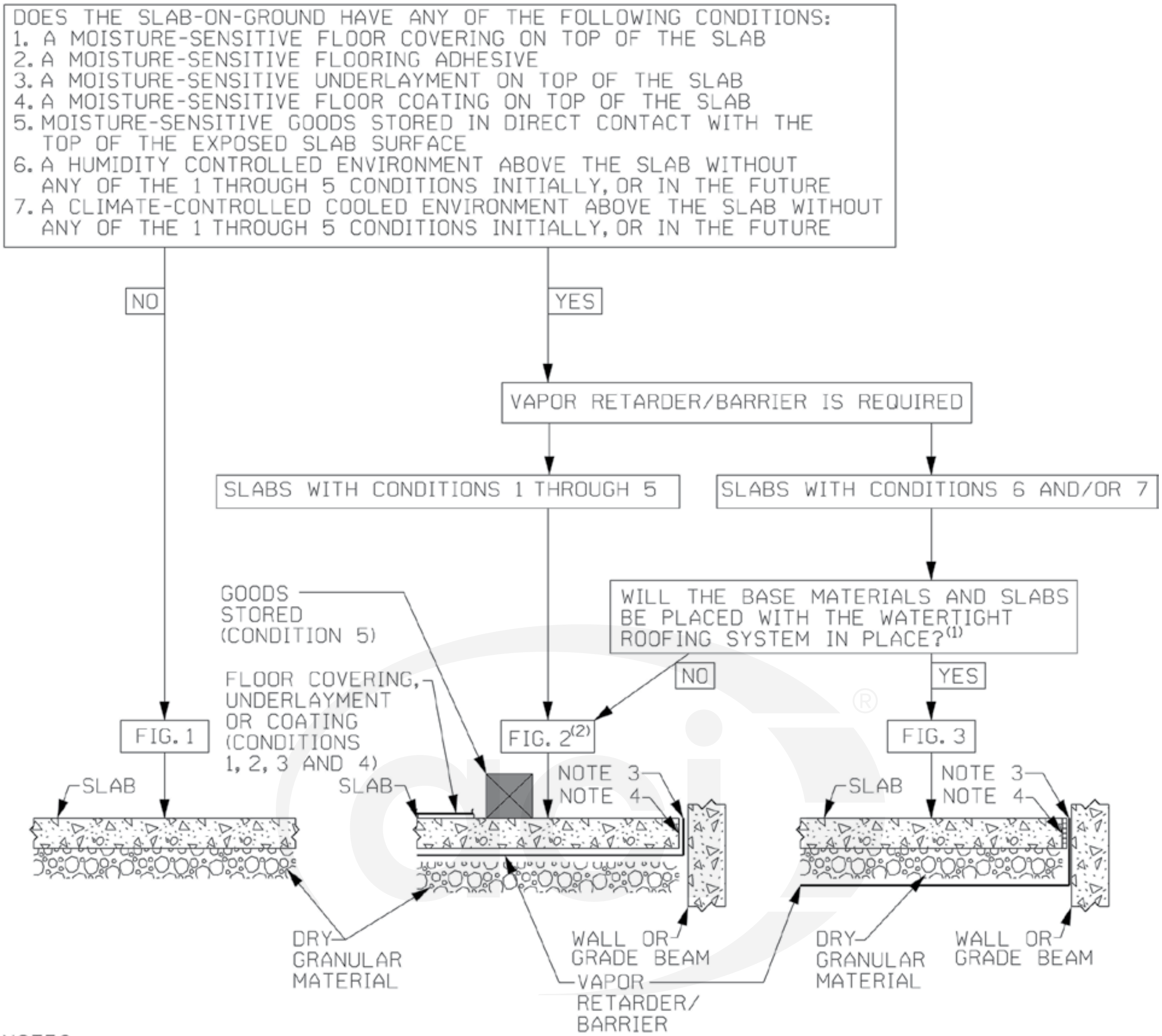
Placing concrete in direct contact with the vapor retarder/barrier requires additional design and construction considerations if potential slab-related problems are to be avoided. When compared with identical concrete cast on a draining base, concrete placed in direct contact with a vapor retarder/barrier shows more settlement and exhibits significantly larger length change in the first hour after casting, during drying shrinkage, and when subject to environmental change (Suprenant 1997). Joints that open wider than what is normally anticipated are called dominant joints (Walker and Holland 2007). Dominant joint behavior can be made worse when the slab is placed in direct contact with a vapor retarder/barrier that reduces friction from the base. Where reinforcing steel is present, settlement cracking over the steel is more likely because of increased settlement resulting from a longer bleeding period. There is also increased potential for a greater measure of slab curl.

Concrete that does not lose excess water to the base does not stiffen as rapidly as concrete that does. If rapid surface drying conditions are present, the surface of concrete placed directly on a vapor retarder/barrier has a tendency to dry and crust over whereas the concrete below the top fraction of an inch (millimeter) remains relatively less stiff or unhardened. When this occurs, it may be necessary to begin machine operations on the concrete surface before the concrete below the top surface is sufficiently set. Under such conditions, a reduction in surface flatness and some blistering or delamination can occur as air, water, or both, become trapped below the finish surface.

Each proposed installation should be independently evaluated for moisture sensitivity of anticipated subsequent floor finishes and the level of protection and material strength they might need. When placing concrete in direct contact with the vapor retarder/barrier, the potential effects of slab curling, crusting, and cracking should be considered. Design and construction measures should be implemented to offset or to minimize these effects. The anticipated benefits and risks associated with the specified location of the vapor retarder/barrier should be reviewed (Fig. 5.2.3.2) with all parties before construction (ACI 302.2R).

5.2.4 *Supporting reinforcement*—Deformed reinforcing steel or post-tensioning tendons should be supported and tied together sufficiently to minimize movement 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 steel or post-tensioning tendons at the proper elevation while maintaining minimum concrete cover requirements.

When welded wire reinforcement is used, its larger flexibility dictates that the contractor pay close attention to establishing and maintaining adequate support of



NOTES:

(1) IF GRANULAR MATERIAL IS SUBJECT TO FUTURE MOISTURE INFILTRATION FROM WET-CURING, WASH-DOWN AREAS SLOPED TO DRAINAGE, OR OTHER LIQUIDS THAT CAN POND ON TOP OF THE SLAB AND SEEP THROUGH JOINTS, CRACKS OR OTHER OPENINGS, USE FIG. 2.

(2) IF FIGURE 2 IS USED, MEASURES TO MINIMIZE SLAB CURLING, DOMINANT JOINTS, DELAMINATIONS, BLISTERING, CRUSTING, PLASTIC SHRINKAGE CRACKING, BAR SHADOWING AND SUBSIDENCE CRACKING LONGITUDINALLY OVER THE REINFORCEMENT, REDUCTION IN SURFACE FLATNESS, AND FINISHING TIME WILL LIKELY BE REQUIRED.

(3) AT THE PERIMETER, VAPOR RETARDER/BARRIER SHOULD BE TURNED UP AND SEALED TO WALL, GRADE BEAM OR SLAB.

(4) FLEXIBLE CLOSED CELL FOAM PLANK FULL DEPTH OF SLAB (WHERE REQUIRED) WITH ELASTOMERIC JOINT SEALANT (WHERE REQUIRED). (NOTE: FOAM PLANK IS NOT SHOWN IN FIG. 2 BUT CAN BE USED AS SHOWN IN FIG. 3)

Fig. 5.2.3.2—Flow chart to determine when and where a vapor retarder/barrier should be used.

the reinforcement during the concrete placing operations (Neuber 2006). Welded wire reinforcement should not be placed on the ground and pulled up after placement of the concrete, nor should the mats be walked in after placing the concrete.

Proper support spacing is necessary to maintain welded wire reinforcement at the proper elevation; supports should be close enough such that welded wire reinforcement cannot be forced out of location by construction foot traffic. Support spacing can be increased when heavier gauge wires or a double mat of small-gauge wires is used. Installation should be in accordance with the Wire Reinforcing Institute's (2008) recommendations.

5.2.5 *Steel fibers*—Steel fibers are used to provide reinforced concrete slabs-on-ground with increased strain strength, impact resistance, flexural toughness, fatigue endurance, crack-width control, and tensile strength (ACI 544.4R). Finishing floors with steel fibers is similar to other floors, except for the potential for steel fibers to become exposed on the surface of the slab. Typically, however, occasional exposed fibers do not cause a problem. Section 7.2.4 discusses types of steel fibers and dosages in detail.

5.2.6 *Synthetic fibers*—Synthetic fibers are used to reinforce concrete against plastic shrinkage and drying shrinkage stresses. Section 7.2.3 discusses types of synthetic fibers and dosages in detail.

5.2.7 *Post-tensioning reinforcement*—The use of high-strength steel tendons as reinforcement instead of conventional mild steel temperature and shrinkage reinforcement introduces 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 drying 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 (Post-Tensioning Institute 1990, 1996). For guidelines on installation details, contact a concrete floor specialty contractor who is thoroughly experienced with this type of installation.

5.2.8 *Causes of cracking over reinforcement*—Bar shadowing and subsidence cracking directly over reinforcement is caused by inadequate consolidation of concrete, inadequate concrete cover over the reinforcement, use of large-diameter bars (Babaei and Fouladgar 1997; Dakhil et al. 1975), higher temperature of reinforcing bars exposed to direct sunlight, higher-than-required slump in concrete, revibration of the concrete, inadequate control of evaporation rate before concrete curing begins, or a combination of these items.

5.2.9 *Joint design*—Joints are used in slab-on-ground construction to limit the frequency and width of random cracks caused by volume changes and to reduce the magnitude of slab curling. Slab designs with an increased number of joints can result in decreases in curling and individual joint opening width, resulting in less overall maintenance. The joint details and layout of joints should be provided by the designer. When the joint layout and joint details are not provided before project bid, the designer should provide a detailed joint layout along with the joint details before the slab preconstruction meeting or commencing construction.

As stated in ACI 360R, every effort should be made to isolate the slab from restraint that might be provided by another element of the structure. Restraint from any source, whether internal or external, will increase the potential for random cracking.

Isolation, contraction, and construction joints are commonly used in concrete slabs-on-ground. Appropriate locations for isolation joints and contraction joints are shown in Fig. 5.2.9. With the designer's approval, construction joint and contraction joint details can be interchanged. Refer to ACI 360R for a detailed discussion of joints. Joints in topping slabs should be located directly over joints in the base slab.

5.2.9.1 *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 that do not require lateral restraint from the slab, columns, equipment foundations, footings, or other points of restraint such as drains, manholes, sumps, and stairways. An isolation joint may be composed of sheet material or a preformed joint material separating two adjacent concrete elements; one example is where a slab abuts a wall. Where the isolation joint will restrain shrinkage, flexible closed-cell foam plank should be used with a thickness that accommodates the anticipated shrinkage movement. The joint material should extend the full depth of the slab or slightly below its bottom to ensure complete separation. Where the joint filler will be objectionably visible, or where there are wet conditions or hygienic or dust-control requirements, the top of the preformed filler can be removed and the joint caulked with an elastomeric sealant. Three methods for producing a relatively uniform depth of joint sealant depth are:

1. Use a saw to score both sides of the preformed filler at the depth to be removed. Insert the scored filler in the proper location. After the concrete hardens, use a screwdriver or similar tool and remove the top section.

2. Cut a strip of wood equal to the desired depth of the joint sealant. Nail the wood strip to the preformed filler

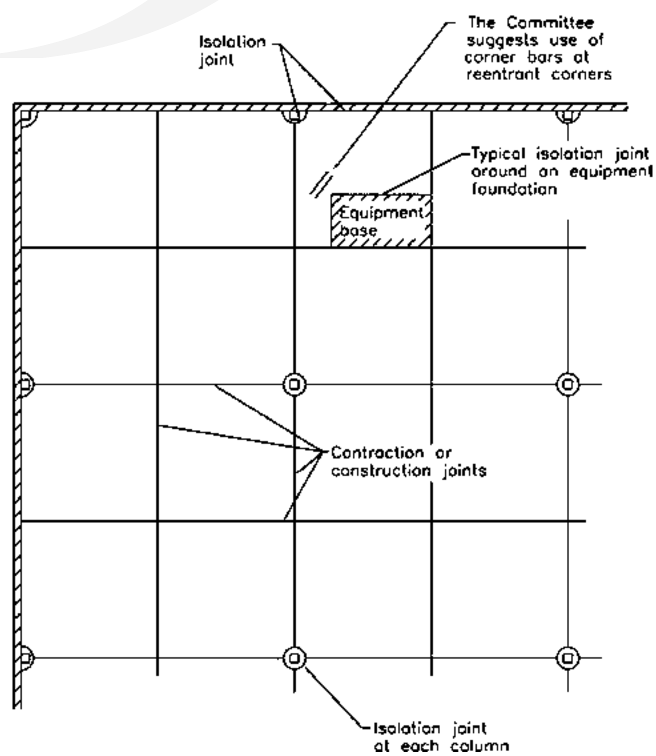


Fig. 5.2.9—Appropriate locations for joints.

and install the assembly in the proper location. Remove the wood strip after the concrete has hardened.

3. Use a premolded joint filler with a removable top portion.

Refer to ACI 223R for guidance on isolation joints for slabs using shrinkage-compensating concrete.

5.2.9.2 *Construction joints*—Construction joints are placed in a slab to define the extent of the individual concrete placements, generally in conformity with a predetermined joint layout. If concrete placement 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, heavy loadings, or both, joints with dowels are recommended. Keyed joints are not recommended where load transfer is required because the two sides of the keyway lose contact when the joint opens due to drying shrinkage.

5.2.9.3 *Contraction joints*—Contraction joints are usually located on column lines with intermediate joints located at equal spaces between column lines, as shown in Fig. 5.2.9. Factors considered when selecting spacing of contraction joints are:

a) Slab design method (ACI 360R)

b) Slab thickness

c) Type, amount, and location of reinforcement

d) Shrinkage potential of the concrete, including cement type and quantity; aggregate type, size, gradation, quantity, and quality; *w*/*cm*; type of admixtures; and concrete temperature

e) Base friction

f) Floor slab restraints

g) Layout of foundations, racks, pits, equipment pads, trenches, and similar floor discontinuities

h) Environmental factors such as temperature, wind, and humidity

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

Floor surface curling at joints is a normal consequence of volume change resulting from differential moisture loss from concrete slab to the surrounding environment. This distortion can lead to conflicts with respect to installation of some floor coverings in the months after concrete placement. Current national standards for ceramic tile and wood flooring, such as gymnasium floors, are two instances that require the concrete slab surface to comply with stringent surface tolerances that cannot be met under typical slab curling behavior. The designer should correlate the slab design with the requirements imposed by the floor covering specification in the design documents. The potential for the joints to telegraph through the flooring should be addressed by the design.

Some random cracking should always be expected, even with sufficiently close joint spacing. It is reasonable to expect random visible cracks to occur in 0 to 3 percent of the surface area floor slab panels formed by saw-cutting, construction joints, or a combination of both. If slab curl is of greater concern than usual, joint spacing, mixture proportion, and joint details should be carefully analyzed. Reinforcement will not prevent cracking. If the reinforcement is properly sized and located, cracks should remain tightly closed.

Joints in either direction can be reduced or eliminated by post-tensioning that introduces 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 223R 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. Plastic or metal inserts are not recommended for constructing or forming a contraction joint in any exposed floor surface that will be subjected to wheeled traffic.

5.2.10 *Saw-cutting joints*—Contraction joints in industrial and commercial floors are usually formed by sawing a continuous slot in the slab to create a weakened plane, below which a crack will form. Further details on saw cutting of joints are given in 10.3.12.

5.2.11 *Joint filling*—Contraction and construction joints in floor areas subject to the hard wheels of material-handling vehicle traffic should be filled with a semi-rigid filler to minimize wear and damage to joint edges. Construction joints should be saw-cut 1 in. (25 mm) deep before filling. Joints should be as narrow as possible to minimize damage due to wheels loads while still being wide enough to be properly filled.

Where wet conditions or hygienic requirements exist, joints should be sealed with an elastomeric liquid sealant or a preformed elastomeric device. If there is also industrial vehicular traffic in these areas, consideration should be given to armoring the edge of the joint through alternative means. Refer to 7.8 for a discussion of joint materials and 11.10 for installation of joint fillers.

5.2.12 *Load-transfer mechanisms*—Use of load-transfer devices at construction and contraction joints is recommended when positive load transfer is required, unless a sufficient post-tensioning force is provided across the joint to transfer the shear. Load-transfer devices force the concrete sections on both sides of a joint to undergo approximately equal vertical displacements when subjected to a load and help prevent damage to an exposed edge when the joint is subjected to vehicles with hard wheels such as lift trucks. Dowel baskets should be used to maintain alignment of dowels when used in contraction joints, and alignment devices should be used in construction joints.

Deformed reinforcing bars should not be continued across contraction joints or construction joints because they restrain joints from opening as the slab shrinks during drying, unless the reinforcement is properly designed as an enhanced aggregate interlock load-transfer mechanism (ACI 360R).

Keyed joints are not recommended for load transfer in slabs-on-ground where heavy-wheeled traffic load is anticipated because 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 joint edges. For long post-tensioned floor strips and floors using shrinkage-compensating concrete with long joint spacing, 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 to accommodate shrinkage and creep (Post-Tensioning Institute 1990, 2000). Where significant slab movement is expected, steel plating of the joint edges is recommended for strengthening the edges.

5.3—Suspended slabs

5.3.1 *Required design elements*—The following items specifically impact the construction of suspended slabs and should be included in the construction documents prepared by the designer:

a) Frame geometry (member size and spacing)

b) Concrete reinforcement (type, size, location, and method of support)

c) Shear connectors, if required

d) Construction joint location and details

e) Steel deck (type, depth, gauge, and installation requirements), if required

f) Shoring, if required

g) Tolerances (forms, structural steel, reinforcement, and concrete)

5.3.2 *Suspended slab types*—In general, suspended floor systems fall into four main categories:

a) Cast-in-place suspended floors

b) Slabs with removable forms

c) Slabs-on-composite and noncomposite steel decking

d) 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-steel decking and topping slabs-on-precast-concrete are hybrid systems that involve design requirements established by The Steel Deck Institute, The American Institute of Steel Construction, Precast/Prestressed Concrete Institute, and tolerances of ACI 117.

The levelness of suspended slabs depends on the accuracy of formwork and strike-off, but is further influenced, especially in the case of slabs-on-steel decking, by the behavior of the structural frame during and after completion of construction. The contractor should recognize that each type of structural frame behaves differently and plan accordingly.

The slab designer should discuss with the owner if the slab surface is to be placed as near level as possible with a varying slab thickness, or if it is more important to have a slab with a uniform thickness, and then design the slab and framing system accordingly. When placing slabs-on-steel decking, the contractor is cautioned that deflections of the structural steel members can vary from those anticipated by the designer. Achieving a level deflected surface can require increasing the slab thickness more than 3/8 in. (9.5 mm) in local areas. Concrete placement procedures, increasing slab thickness to place level surfaces, and the basis for acceptance of the levelness of a completed concrete floor surface should be established and agreed upon by key parties before beginning suspended floor construction (Tipping 1992). In many cases, the deflection will not allow a level slab to be placed.

5.3.3 *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 will deflect when supporting shores are removed.

Post-tensioned systems are normally used when larger spans are necessary or when the structural system is relatively shallow for the spans considered. Post-tensioned systems use high-strength steel tendons that are tensioned after the concrete hardens using a hydraulic jack designed for that purpose. 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 magnitude of deflection in a conventionally reinforced floor system depends 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 designer, an initial camber, generally 1/2 in. (13 mm) or more, can be required. The amount of camber is determined by the designer based on an assessment of the loading conditions discussed. Ideally, the cambered floor system will deflect down to a level position after removal of the supporting shores.

5.3.4 *Slabs-on-carton forms*—Slabs-on-carton forms are a special application of slabs with removable forms (Tipping and North 1998). These slabs are necessary when slabs at ground level should remain independent of soil movement. Slabs-on-carton forms are most commonly used when soils at the building site are expansive clays subject to significant movement as a result of moisture variation. They provide a more economical construction solution than conventional framing systems, which require a crawl space to remove forms. The cardboard carton forms deteriorate in the months following construction, eventually leaving the desired void space below the slab and forcing the slab to span between supporting foundation elements.

Experience has shown that certain types of wet cardboard carton forms can fail locally under the weight of concrete and construction activities, resulting in a loss of part or all of the desired void space in the vicinity of the form failure. This failure can occur immediately or up to 30 or 45 minutes after strike-off. The latter type of failure, in addition to reducing desired void space, can result in a loss of local slab levelness. Forms that have been damaged by rain should be replaced or allowed to dry thoroughly, with their capacity verified, before concrete placement.

5.3.5 *Slabs-on-steel-deck*—Construction of slabs-on-steel-deck involves the use of a concrete slab and a supporting platform consisting of structural steel and steel deck. The structural steel can be shored or unshored at the time of concrete placement. The steel 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-steel-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 strike-off of the concrete surface of a slab-on-steel-deck, unless the frame is preloaded to allow deflection to take place before strike-off and slab thickness is allowed to vary.

5.3.6 *Composite slabs-on-steel-deck*—In composite construction, the composite section, which consists of the 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 with a resulting load-carrying element that is configured much like a capital T. The steel beam forms the stem of the T, and the floor slab forms the crossbar. Construction joints that are parallel to structural steel beams should be located far enough away to eliminate their impact on composite behavior. Questions about the location of construction joints should be referred to the project designer (Ryan 1997).

Unshored composite construction is the more common method used by designers because it is 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 (Tipping 2002).

Shored composite concrete slabs-on-steel-deck are similar to slabs with removable forms; both are supported until the concrete has been placed and reaches the required strength. Structural steel floor framing members for shored composite slabs-on-steel 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 an aesthetic problem. The contractor is cautioned that this issue and any measures taken by the designer to avoid the formation of this type of crack should be addressed to the satisfaction of key parties before beginning suspended floor construction.

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

5.3.8 *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 scheduling such operations to minimize the potential impact of these variations. The potential for significant variations in the preplacement camber of supporting precast members and the relative lack of options associated with field changes or modifications create a unique challenge to the contractor when the desire is to produce a surface that is uniformly level or uniformly sloped. It is imperative that preplacement discussions be held concerning anticipated deflection, minimum required topping thickness, and allowable increase in topping thickness beyond that required by the drawings that may be necessary to achieve the desired product. A preplacement survey of the erected precast is a critical component of those discussions.

5.3.9 *Reinforcement*—For cast-in-place concrete suspended slabs, reinforcing steel location varies as dictated by the construction documents. The reinforcement amount as a minimum should meet the ACI 318 building code requirements. However, for slabs that will have surfaces exposed to view, the slab designer should discuss with the owner any additional reinforcement that may be required to control the crack widths to meet the owner's crack width expectations. It should be noted that, for exposed slabs, the minimum amount of steel required by the building code may not be sufficient to meet the owner's expectations for crack widths (ACI 224R). For suspended slabs supporting vehicular traffic such as cars, trucks, and lift trucks, reinforcement amounts should be carefully considered to maintain the crack width sufficiently tight to minimize crack spalling due to this fatigue-loading condition (ACI 215R). Post-tensioning reinforcement, when used, is enclosed in a plastic or metal sleeve, unbonded, and tensioned by a hydraulic jack after the concrete reaches sufficient compressive strength. Elongation and subsequent anchoring of the ends of post-tensioning tendons result in the transfer of compressive force to the concrete (Post-Tensioning Institute 1990).

5.3.10 For slabs-on-composite-steel-deck, the composite steel deck provides the positive moment reinforcement for static gravity loads and, if needed, negative moment reinforcement can be used. Composite steel deck is not recommended as the only reinforcement for use in applications where the floor is subjected to repeated vehicular traffic such as lift trucks or similar heavy wheeled traffic (ANSI/SDI C-2011). Temperature and shrinkage reinforcement for composite steel deck slabs can be provided by deformed reinforcing steel, welded wire reinforcement, steel fibers, macrosynthetic fibers, or a combination thereof (ANSI/SDI C-2011). For noncomposite slabs, the reinforcement is the same as for cast-in-place suspended slabs with the steel deck acting as a stay-in-place form (ANSI/SDI NC-2010).

5.3.11 *Construction joints*—The designer should provide criteria for location of construction joints in suspended slabs. The following is a general discussion of criteria that can influence these decisions.

5.3.11.1 *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.

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

The following are general guidelines for deciding on the location of construction joints in composite slabs-on-steel-deck:

a) Construction joints that parallel secondary structural steel beams should be placed near the middle third of the slab between beams.

b) Construction joints that parallel primary structural steel beams and cross secondary structural steel beams should be placed near the primary beam. The primary structural steel beam should be excluded from the initial placement. Place the construction joint far enough away from the primary beam 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 construction joint location allows nearly the full dead load from concrete placement to be applied to secondary beams that are included in the initial concrete placement. The primary beam should generally be included in the second placement at the construction joint. This will allow the primary beam to deflect completely before concrete at the primary beam hardens; construction joints that cross primary structural steel beams should be placed near a support at one end of the primary beam. This will allow the beam to deflect completely before concrete at the beam hardens.

5.3.11.3 *Noncomposite slabs-on-steel-deck*—The placement of construction joints in noncomposite slabs-on-steel-deck should follow the same general guidelines discussed for slabs-on-removable-forms in 5.3.11.1.

5.3.11.4 *Topping slabs-on-precast-concrete*—Construction joints in topping slabs-on-precast-concrete should be placed over joints in the supporting precast concrete.

5.3.12 *Cracks in slabs-on-steel-deck*—Cracks often develop in slabs-on-steel-deck. These cracks can result from loadings, drying shrinkage, thermal contraction, or variations in flexibility of the supporting structural steel and steel 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 steel deck, which is often designed for strength rather than for flexibility consideration.

Vibration as a result of power floating and power troweling operations can produce cracking over the structural steel beams during concrete finishing operations if the steel deck is flexible. As the concrete cures and shrinks, these cracks will open wide if not restrained by reinforcing steel—usually deformed or welded wire reinforcement—located near the top surface of the slab. Steel and macrosynthetic fibers have also been effective in controlling crack widths.

5.4—Miscellaneous details

5.4.1 *Heating ducts*—Heating ducts embedded in a concrete slab can be 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.

5.4.2 *Edge insulation*—Edge insulation for slabs-on-ground is desirable in most heated buildings. The insulation should be in accordance with ANSI/ASHRAE/IES 90.1. It should not absorb moisture; be resistant to fungus, rot, and insect damage; and 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 configuration adjacent to the inside of the foundation and under the edge of the slab. If the L-shape configuration is used, the installation should extend horizontally under the slab a total distance of 24 in. (600 mm).

5.4.3 *Radiant heating: piped liquids*—Slabs can be heated by circulating heated liquids through embedded piping. Ferrous, copper, or plastic pipe is generally used with not less than 1 in. (25 mm) of concrete under the pipe and 2 to 3 in. (50 to 75 mm) of concrete cover over the pipe. The slab is usually monolithic and the concrete 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 distress during the service life.

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 concrete placement should be inorganic and nonabsorbent; precast concrete bar supports 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 or construction joint, a 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 by air pressure, but not water pressure, and should be maintained in the pipe during concrete placement operations. After concreting, the slab should not be heated until concrete curing 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.

5.4.4 *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 to 3 in. (25 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 to avoid the creation of a horizontal cold joint (ASHVE 1955).

Calcium chloride should not be used where copper 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.

5.4.5 *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 freezing-and-thawing resistance. Concrete surfaces should have a slope not less than 1/4 in./ft (20 mm/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 admixtures should not be used with snow-melting systems. Experience has shown that these snow-melting piping systems demand high energy consumption while displaying a high potential for failure and thermal cracking.

5.4.6 *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 on both the top and bottom.

5.4.7 *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. If not properly 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.