ACI 302.1R-04

Guide for Concrete Floor and Slab Construction

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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, 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 will never be the same, the shrinkage will vary throughout the depth, causing the as-cast shape to be distorted and reduced in volume.

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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 crack-free and curl-free floors. Consequently, every owner should be advised by both the designer and contractor that it is normal to expect some amount of cracking and curling on every project, and that such occurrence does not necessarily reflect adversely on either the adequacy of the floor's design or the quality of its construction (Ytterberg 1987; Campbell et al. 1976).

Refer to the latest edition of ACI 360R for a detailed discussion of shrinkage and curling in slabs-on-ground. Refer to the latest edition of ACI 224R 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 aspects of construction such as site preparation, concreting materials, concrete mixture proportions, concreting 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; concrete; consolidation; contract documents; curing; curling; deflection; durability; form; fracture; joint; mixture proportioning; mortar, paste, placing; quality control; slab-on-ground; slabs; slump test; specification.

CONTENTS

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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 normalweight and structural lightweight concrete floors and slabs made with conventional portland and blended cements. Slabs specifically intended for the containment of liquids are beyond the scope of this document.

The design of slabs-on-ground should conform to the recommendations of ACI 360R. Refer to ACI 223 for procedures 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. 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. This guide emphasizes choosing and proportioning of materials, design details, proper construction methods, and workmanship.

1.1.1 *Prebid meeting*—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 herein. Accordingly, contractors and suppliers are urged to make a thorough review of contract documents before bid preparation.

The best forum for such a review is the prebid meeting. This meeting offers bidders an opportunity to ask questions and clarify their understanding of contract documents before 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 the designer require a preconstruction meeting to be held to establish and to 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 following 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 strength, flexural strength, or both, and finishability (Section 6.2);
    b. Minimum cementitious material content, if applicable (Table 6.2);
    c. Maximum size, grading, and type of coarse aggregate;
    d. Grading and type of fine aggregate;
    e. Combined aggregate grading;
    f. Air content of concrete, if applicable (Section 6.2.7);
    g. Slump of concrete (Section 6.2.5);
    h. Water-cement ratio (w/c) or water-cementitious material ratio (w/cm); and
    i. 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, length of curing, necessary protection, and time before opening slabs for traffic (ACI 308R);
17. Testing and inspection requirements; and
18. Acceptance criteria and remedial measures to be used, if required.

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 and ANSI/ASCE 9 [Section 12.1]);
3. Form stripping procedures, if applicable; and
4. Items listed in Section 3.3 that are appropriate to the structural system(s) used for the project.

1.1.3 *Quality assurance*—Adequate provisions 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 ensuring a high-quality finished product, the specifier or owner should consider requiring the use of prequalified concrete contractors, concrete suppliers, accredited 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 certify concrete flatwork finishers and concrete inspectors and testing technicians throughout the United States, Mexico, and Canada.

1.2—Terminology

adjusted mix optimization indicator (MOI-Adj)—intersection of the coarseness factor value and the adjusted workability factor on the coarseness factor chart.

adjusted workability factor (W-Adj)—the workability factor adjusted for cementitious content. For each 94 lb (43 kg) of total cementitious material above 564 lb/yd^3 (335 kg/m^3), increase the workability factor by 2.5%. For each 94 lb (43 kg) of total cementitious material below 564 lb/yd^3 (335 kg/m^3), decrease the workability factor by 2.5%. (Example for a workability factor of 33% and 600 lb/yd^3 [356 kg/m^3] of cementitious material: 600 lb/yd^3 [356 kg/m^3] – 564 lb/yd^3 [335 kg/m^3] = 36 lb/yd^3 [21 kg/m^3]; 36 lb [16 kg]/94 lb [43 kg] = 0.38; 0.38 × 2.5% = 0.95%; W-Adj = 33% workability factor + 0.95% = 33.95%).

coarseness factor—the percentage of combined aggregate that is larger than the 3/8 in. (9.5 mm) sieve, divided by the percentage of combined aggregate that is larger than the No. 8 (2.36 mm) sieve, expressed as a percent. (Example: 33% retained on the 3/8 in. [9.5 mm] sieve/45% retained on the No. 8 [2.36 mm] sieve = 73.3%).

differential set time—the difference in timing of initial power floating of sequential truck loads of concrete as they are delivered to the jobsite.

dry shake—metallic or mineral hardener mixed with cement and applied dry to the surface of concrete during finishing operations.

floating—a term used to describe smoothing and subsequent compaction and consolidation of the unformed concrete surface.

mix optimization indicator (MOI)—intersection of the coarseness factor value and the workability factor on the coarseness factor chart.

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

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

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

water slump—the magnitude of slump, measured in accordance with ASTM C 143, which is directly attributed to the amount of water in the concrete mixture.

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

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

1.3—Related work of other committees

1.3.1 *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 reference 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.

311—Develops guides and procedures for inspection and testing.

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.

350—Develops and updates code requirements for concrete in environmental structures.

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.

435—Provides recommendations for deflection control in concrete slabs.

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 workers.

1.3.2 *The American Society of Civil Engineers*—ASCE publishes documents that can be helpful for floor and slab construction. Two publications that deal with suspended slab construction are ASCE Standard for the Structural Design of Composite Slabs (ANSI/ASCE 3) and ASCE Standard Prac-

Table 2.1—Classes of floors on the basis of intended use and the suggested final finish technique

Class	Anticipated type of traffic	Use	Special considerations	Final finish
1. Single course	Exposed surface—foot traffic	Offices, churches, commercial, institutional, multi-unit 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, multi-unit 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 tolerance, curing *Unbonded topping*—bondbreaker 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 or 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-troweling
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). Mineral or metallic 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 Classes 4, 5, or 6	Unbonded topping—on new or old floors where construction sequence or schedule dictates	Bondbreaker on base slab, minimum thickness 4 in. (100 mm), abrasion resistance, curing	As in Classes 4, 5, or 6
9. Single course or topping	Exposed surface—superflat or critical surface tolerance required. Special materials-handling vehicles or robotics requiring specific tolerances	Narrow-aisle, high-bay warehouses; television studios, ice rinks, or gymnasiums. Refer to ACI 360R for design guidance	Varying concrete quality requirements. Special application procedures and strict attention to detail are recommended when shake-on hardeners are used. F_F 50 to F_F 125 (“superflat” floor). Curing	Strictly following techniques as indicated in Section 8.9

tice for Construction and Inspection of Composite Slabs (ANSI/ASCE 9).

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. Intended use requirements should be considered when selecting concrete properties (Section 6.2), 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 and impact 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, finishing, curing, and other 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 final finishing techniques. If abrasion from grit or other materials is anticipated, a higher-quality floor surface may be required for satisfactory service (ASTM 1994). Under these conditions, a higher-class floor, a special mineral or metallic 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 compressive strength than the base course. Class 8 floors can also make use of an embedded hard aggregate, a premixed (dry-shake) mineral aggregate, or metallic hardener for addition to the surface (Section 5.4.5).

Class 3 (with unbonded topping) and Class 8 floors are used when it is preferable to not 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 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 nonindustrial applications, whereas Class 8 floors are primarily for industrial applications.

Plastic sheeting, roofing felt, or a bond-breaking compound is 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 should be coordinated with joint spacing in the base slab.

Additional joints should be considered if the topping slab thickness mandates a closer spacing than the base slab to limit uncontrolled cracking and slab curl. Curl or warping will be more probable due to the effects of drying from the top surface only.

2.3.2 *Bonded topping over base slab*—Class 3 (bonded topping) and Class 7 floors use 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 applications subject to heavy traffic and impact. The base slabs can either be 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 (before 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 5.4.5). Bonded concrete toppings should have a minimum thickness of 3/4 in. (19 mm). Proprietary products should be applied per manufacturers' recommendations. Joint spacing in the topping should be coordinated with construction and contraction joint spacing in the base slab. Saw-cut contraction joints should penetrate into the base slab a minimum of 1 in. (25 mm).

If the topping is placed on a base slab before the joints are cut, joints in the topping should extend into the base slab and depth should be appropriate for the total thickness of the combined slab. If the topping is installed on a previously placed slab where joints have activated, additional joints in the topping are unnecessary as shrinkage relief cannot occur between the slab joints in the bonded topping. When topping slabs are placed on shrinkage-compensating base slabs, the joints in the base slab can only be reflected in the bonded topping slab if the bonded topping slab is installed shortly after the maximum expansion occurs. Maximum expansion usually occurs within seven to 14 days.

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 require 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 the design of concrete floors as it relates to their constructibility. 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 for structural design of composite slabs, and ANSI/ASCE 9 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 *Required design elements*—The following items should be specified in the contract documents prepared by the designer:

- Base and subbase materials, preparation requirements, and vapor retarder, if required;
- Concrete thickness;

- Concrete compressive strength, flexural strength, or both;
- Concrete mixture proportion requirements;
- Joint locations and details;
- Reinforcement (type, size, and location), if required;
- Surface treatment, if required;
- Surface finish;
- Tolerances (base, subbase, slab thickness, and surface);
- Concrete curing;
- Joint filling material and installation;
- Special embedments; and
- 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; therefore, 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 the results from in-place tests of moisture content or density are. 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. For detailed information on soil-support systems, refer to ACI 360R.

3.2.3 *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.

A vapor retarder is a material that is intended to minimize the transmission of moisture upward through the slab from sources below. The performance requirements for plastic vapor retarder materials in contact with soil or granular fill under concrete slabs are listed in ASTM E 1745. It is generally recognized that a vapor retarder should have a permanence (water vapor transmission rate) of less than 0.3 perms, as determined by ASTM E 96.

The selection of a vapor retarder or barrier material should be made on the basis of protective requirements and the moisture-related sensitivity of the materials to be applied to the floor surface. Although conventional polyethylene film with a thickness of as little as 6 mils (0.15 mm) has been used, the committee strongly recommends that the material be in compliance with ASTM E 1745 and that the thickness be no less than 10 mils (0.25 mm). The increased thickness offers increased resistance to moisture transmission while providing greater durability during and after installation.

A number of vapor retarder materials have been incorrectly referred to and used by designers as vapor barriers. True vapor barriers are products that have a permanence (water-vapor transmission rating) of 0.00 perms when tested in accordance with ASTM E 96. The laps or seams in either a vapor retarder or barrier should be overlapped 6 in. (150 mm) (ASTM E 1643) or as instructed by the manufacturer. The joints and penetrations should be sealed with the manufacturer's recommended adhesive, pressure-sensitive tape, or both.

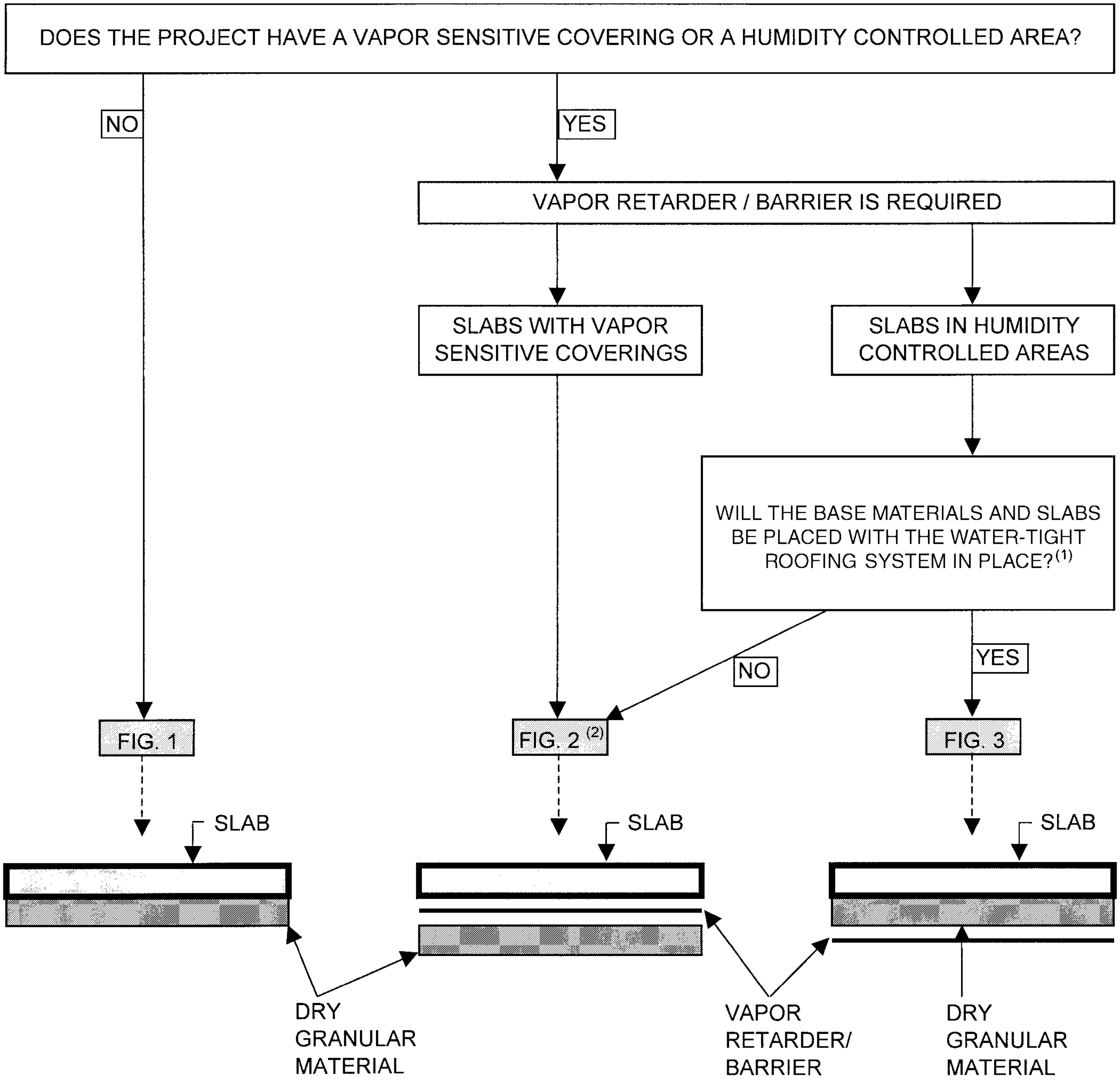
The decision whether to locate the vapor retarder or barrier in direct contact with the slab or beneath a layer of granular fill should be made on a case-by-case basis (Suprenant and Malisch 1998b). For moisture-sensitive flooring materials and environments, placing concrete in direct contact with the vapor retarder or 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 can significantly increase the time required for a slab to dry to levels required by the manufacturers of floor coverings, adhesives, and coatings.

Placing concrete in direct contact with the vapor retarder or barrier, however, requires additional consideration 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 or barrier has been shown to exhibit significantly larger length change in the first hour after casting, during drying shrinkage, and when subject to environmental change; there is also more settlement (Suprenant 1997). Care should be taken in design detailing to minimize restraint to such movement (Anderson and Roper 1977). Where reinforcing steel is present, settlement cracking over the steel is more likely because of the increased settlement resulting from a longer bleeding period. The potential for a greater measure of slab curl is also increased.

Concrete that does not lose water to the base does not stiffen as rapidly as concrete that does lose part of its excess water to the base. If rapid, surface drying conditions are present, the surface of concrete placed directly on a vapor retarder will have a tendency to dry and crust over while the concrete below the top fraction of an inch 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.

The committee recommends that each proposed installation be independently evaluated as to the moisture sensitivity of subsequent floor finishes, anticipated project conditions, and the potential effects of slab curling, crusting, and cracking. The anticipated benefits and risks associated with the specified location of the vapor retarder should be reviewed with all appropriate parties before construction. Figure 3.1 can be used to assist this evaluation process.

3.2.4 *Reinforcement for crack-width control*—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 (Dakhil, Cady, and Carrier 1975; CRSI 1990). This reinforcement is normally furnished in the form of deformed steel bars, welded wire reinforcing, steel fibers, or post-



NOTES:

(1) IF GRANULAR MATERIAL IS SUBJECT TO FUTURE MOISTURE INFILTRATION, USE FIG. 2.
(2) IF FIGURE 2 IS USED, A REDUCED JOINT SPACING, A LOW SHRINKAGE MIX DESIGN, OR OTHER MEASURES TO MINIMIZE SLAB CURL WILL LIKELY BE REQUIRED.

Fig. 3.1—Decision flow chart to determine if a vapor retarder/barrier is required and where it is to be placed.

tensioning tendons. Combinations of various forms of reinforcement have proved successful.

Normally, the amount of reinforcement used in nonstructural slabs is too small to have a significant influence on restraining movement resulting from volume changes. Refer to Section 3.2.5 for a detailed discussion of the relationship between joint spacing and amount of reinforcement.

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 within the upper third of slab thickness, whichever is closer to the surface (CRSI 2001; Snell 1997). Reinforcement should extend to within 2 in. (50 mm) of the slab side edge.

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 the reinforcement during the concrete placing operations. 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 that the welded wire reinforcement cannot be forced out of location by construction foot traffic. Support 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 reduce the possibility of shrinkage and temperature cracks in an adjacent panel. Where the reinforcement is continued through the joint, cracks are likely to occur in adjacent panels because of restraint at the joint (WRI/CRSI 1991). When used in sufficient quantity, reinforcement will hold out-of-joint cracks tightly closed. Some designers prefer partial discontinuance of the reinforcement at contraction joints to obtain some load-transfer capacity without the use of dowel baskets. Refer to 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 mild steel 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. Use of steel fibers through the contraction joints reduces the width of joint openings and that increases the likelihood of cracking occurring between joints. The crack width, however, should remain narrow and, in most cases, there are nondetectible microcracks providing sufficient quantities of fibers used for the given slab joint spacing and thickness, and subgrade conditions and concrete material shrinkage properties are taken into consideration.

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 with hardening of concrete, however, most synthetic fibers at typical dosage rates recommended by the fiber manufacturers will not provide sufficient restraint to inhibit cracking.

3.2.4.3 *Post-tensioning reinforcement*—The use of high-strength steel tendons as reinforcement instead of conventional mild steel 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 (PTI 1990; PTI 1996). 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 consolidation of concrete, inadequate concrete cover over the reinforcement, use of large diameter bars (Dakhil, Cady, and Carrier 1975), higher temperature of reinforcing 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 and to reduce the magnitude of slab curling. Generally, if limiting the number of joints by increasing the joint spacing can be accomplished without increasing the number of random cracks, floor maintenance 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 designer before proceeding.

As stated in ACI 360R, every effort should be made to isolate the slab from restraint that might be provided by 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. 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.

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 members. 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

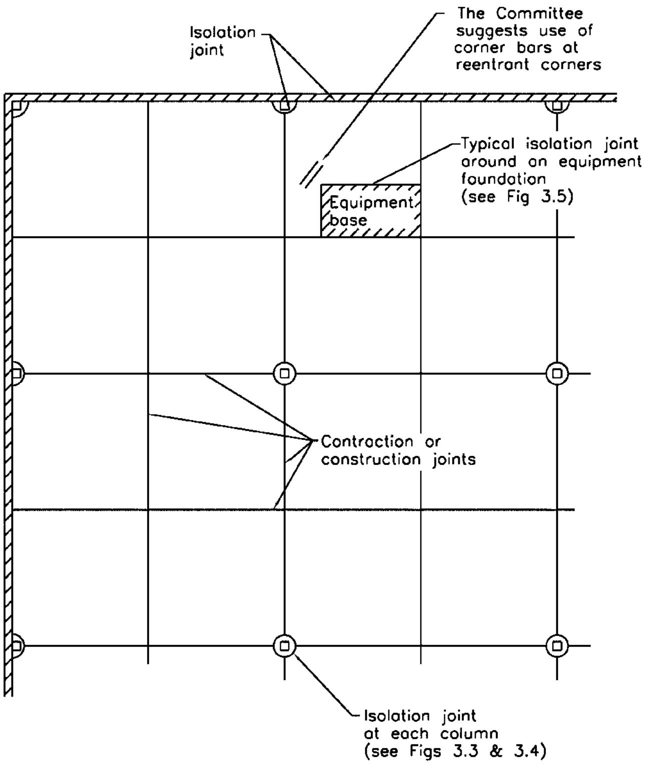


Fig. 3.2—Appropriate locations for joints.

between the floor and the adjacent member. The joint material should extend the full depth of the slab and not protrude above it. The joint filler will be objectionably visible where there are wet conditions, or hygienic or dust-control requirements. Two methods of producing a relatively uniform depth of joint sealant are as follows:

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 Fig. 3.3 and 3.4 for typical isolation joints around columns. Figure 3.5 shows an isolation joint at an equipment foundation.

Isolation joints for slabs using shrinkage-compensating concrete should be dealt with 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 concrete 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, heavy loadings, or both, joints with dowels are recommended (Fig. 3.6). Refer to Section 3.2.7 for a detailed discussion on dowel joints. 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 (Section 3.2.7).

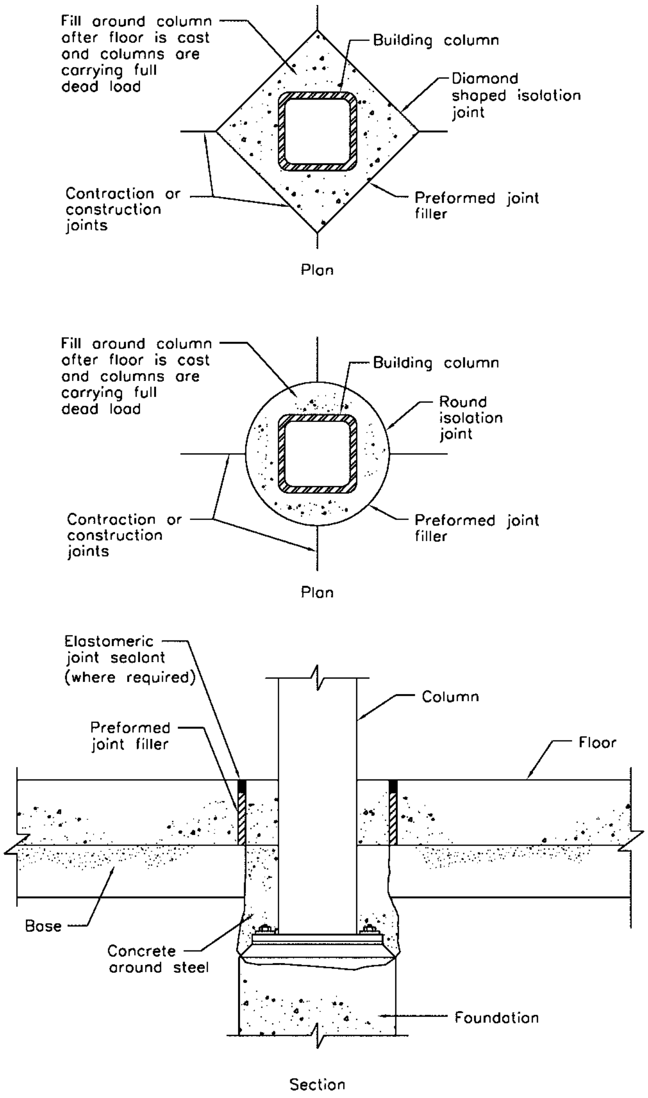


Fig. 3.3—Typical isolation joints at tube columns.

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. The following factors are normally considered when selecting spacing of contraction joints:

- Method of slab design (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; *w/cm*; 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; and

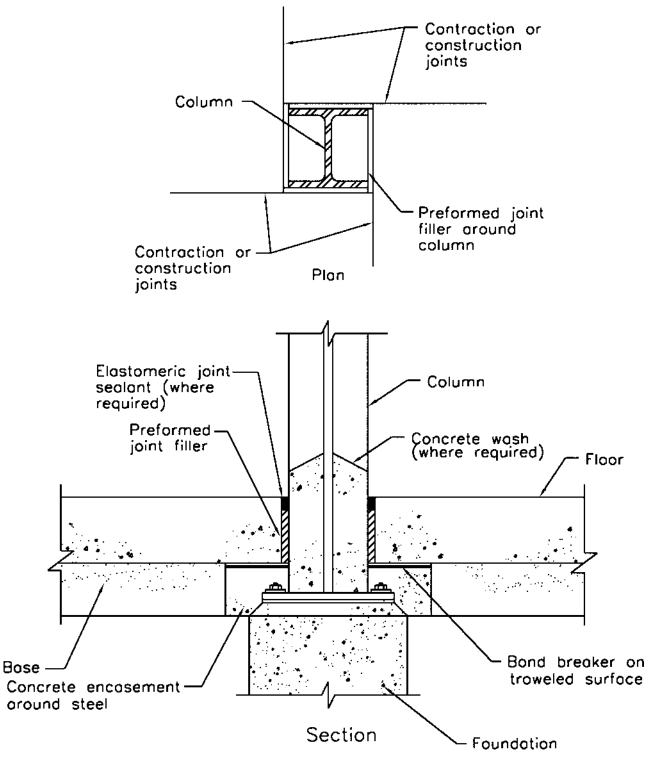


Fig. 3.4—Typical isolation joint at wide flange column.

- 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.

Curling of the floor surface at joints is a normal consequence of volume change resulting from differential moisture loss from concrete slab to the surrounding environment. This distortion can result in conflict 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 consider the requirements for successful installation of floor coverings contained in Division 9 of the project specifications when performing the concrete slab design (ACI 360R).

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 produced acceptable results. Some random cracking should be expected; a reasonable level might be random visible cracks to occur in 0 to 3% 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.

Joint spacing in nominally reinforced slabs (approximately 0.2% steel placed within 2 in. [50 mm] of the top of the slab) can be increased somewhat beyond that recommended for unreinforced, plain concrete slabs, but the incidence of random cracking and curling will increase. Reinforcement will not prevent cracking. If the reinforcement is properly sized and located, cracks that do occur should remain tightly closed.

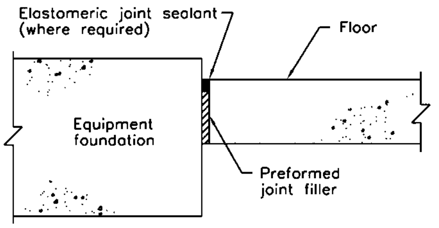


Fig. 3.5—Typical isolation joint around an equipment foundation.

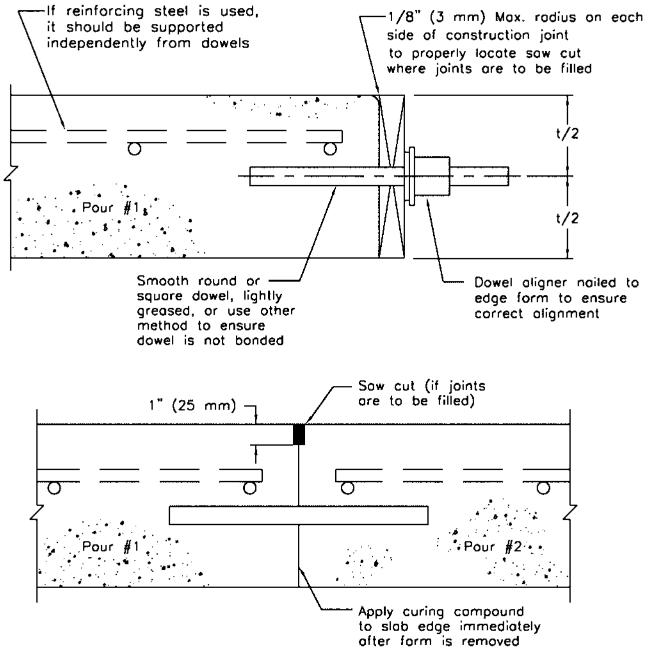


Fig. 3.6—Typical doweled construction joint.

Contraction joints can be reduced or eliminated in slabs reinforced with at least 0.5% 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 top surface. This will typically produce a larger number of closely spaced fine cracks throughout the slab.

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 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. Figure 3.7 shows various types of contraction joints. Floors around loading docks have a tendency to crack due to their configuration and restraints.

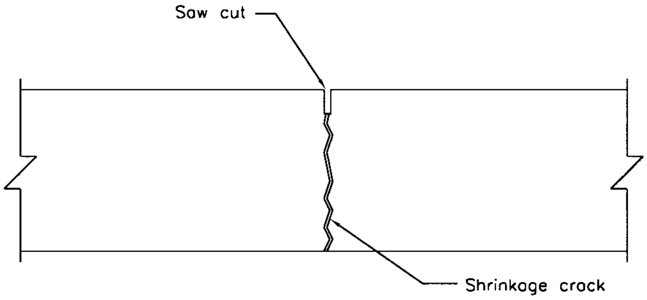


Fig. 3.7—Saw-cut contraction joint.

Figure 3.8 shows two methods that can be used to minimize slab cracking at reentrant corners of loading docks.

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.

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 result in a weakened plane, below which a crack will form (Fig. 3.7). Further details on saw cutting of joints are given in Section 8.3.12

3.2.6 *Joint filling*—Contraction and construction joints in floor areas subject to the hard wheels of material handling vehicle traffic should be filled with a semirigid 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 strengthening the edge of the joint through alternative means.

Refer to Section 5.12 for a discussion of joint materials, Section 9.10 for installation of joint fillers, and ACI 504R for joint sealants.

3.2.7 *Load-transfer mechanisms*—Doweled construction and contraction joints (Fig. 3.6 and 3.9) are recommended when load transfer is required, unless a sufficient post-tensioning force is provided across the joint to transfer the shear. Dowels force the concrete sections on both sides of a joint to undergo approximately equal vertical displacements subjected to a load and help prevent damage to an exposed edge when the joint is subjected to vehicles with hard-wheels such as forklifts. Table 3.1 provides recommended dowel sizes and spacing for round, square, and rectangular dowels. 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. All dowels should be sawn and not sheared. Properly aligned, smooth dowels allow the joint to open as concrete shrinks. Dowel baskets (Fig. 3.9 to 3.11) should be used to maintain alignment of dowels in contraction joints, and alignment devices similar to the one shown in Fig. 3.6 should be used when detailing the doweled construction joints. Dowels should be placed no closer than 12 in. (300 mm) from the intersection of any joints.

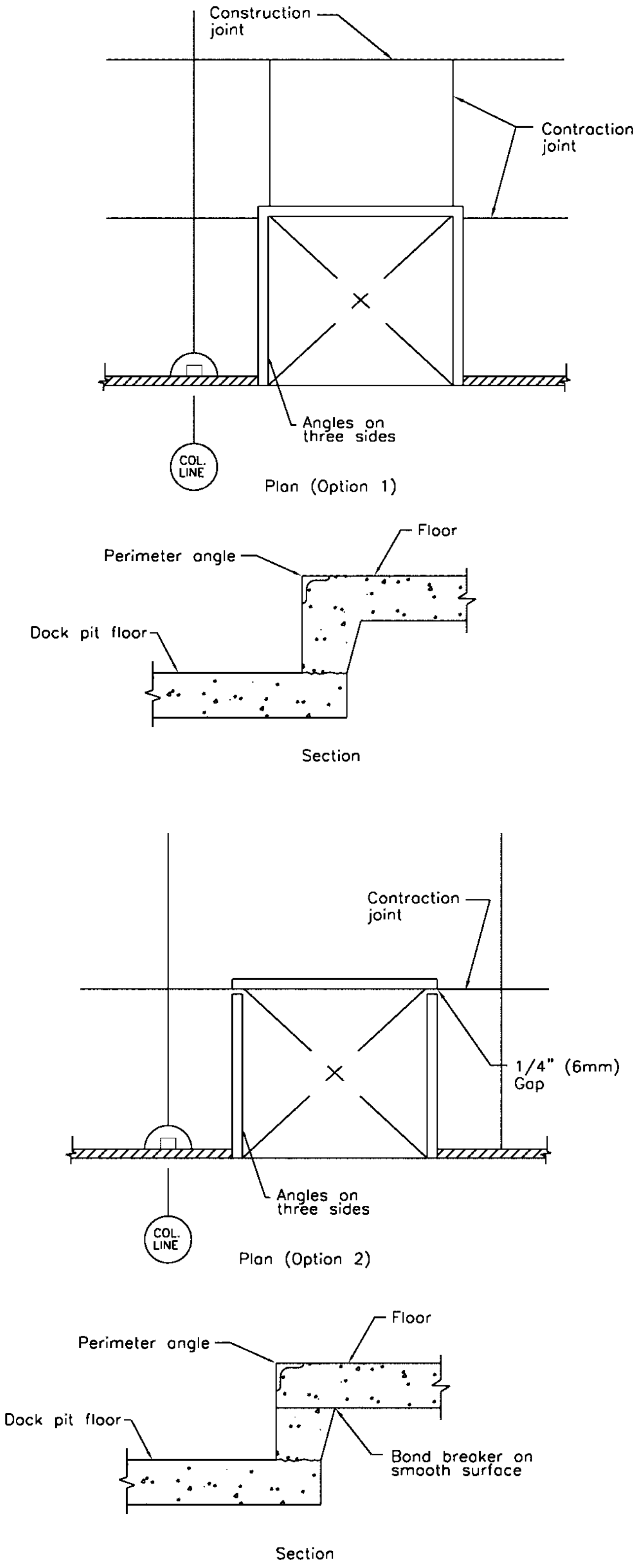


Fig. 3.8—Joint details at loading dock.

Diamond-shaped load plates (a square plate turned so that two corners line up with the joint, Fig. 3.12) can be used to replace dowels in construction joints (Walker and Holland 1998). The diamond shape allows the slab to move horizontally without restraint when the slab shrinkage opens the joint (Fig. 3.13). Table 3.2 provides the recommended size and

Table 3.1—Dowel size and spacing for round, square, and rectangular dowels (ACI Committee 325 1956)

Slab depth, in. (mm)	Dowel dimensions*, in. (mm)			Dowel spacing center-to-center, in. (mm)		
	Round	Square	Rectangular†	Round	Square	Rectangular
5 to 6 (125 to 150)	3/4 x 14 (19 x 350)	3/4 x 14 (19 x 350)	3/8 x 2 x 12 (10 x 50 x 300)	12 (300)	14 (350)	19 (475)
7 to 8 (175 to 200)	1 x 16 (25 x 400)	1 x 16 (25 x 400)	1/2 x 2-1/2 x 12 (12 x 60 x 300)	12 (300)	14 (350)	18 (450)
9 to 11 (225 to 275)	1-1/4 x 18 (30 x 450)	1-1/4 x 18 (30 x 450)	3/4 x 2-1/2 x 12 (19 x 60 x 300)	12 (300)	12 (300)	18 (450)

*Total dowel length includes allowance made for joint opening and minor errors in positioning dowels.

†Rectangular plates are typically used in contraction joints.

Notes: Table values based on a maximum joint opening of 0.20 in. (5 mm). Dowels must be carefully aligned and supported during concrete operations. Misaligned dowels cause cracking.

Table 3.2—Dowel size and spacing for diamond-shaped load plates

Slab depth, in. (mm)	Diamond load plate dimensions, in. (mm)	Diamond load plate spacing center-to-center, in. (mm)
5 to 6 (125 to 150)	1/4 x 4-1/2 x 4-1/2 (6 x 115 x 115)	18 (450)
7 to 8 (175 to 200)	3/8 x 4-1/2 x 4-1/2 (10 x 115 x 115)	18 (450)
9 to 11 (225 to 275)	3/4 x 4-1/2 x 4-1/2 (19 x 115 x 115)	20 (500)

Notes: Table values based on a maximum joint opening of 0.20 in. (5 mm). The construction tolerances required make it impractical to use diamond-shaped load plates in contraction joints.

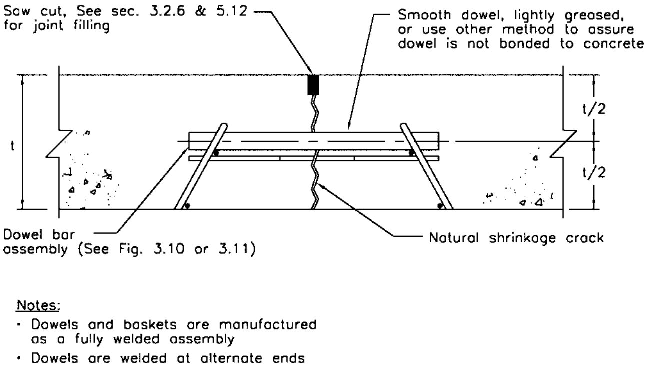


Fig. 3.9—Typical doweled contraction joint.

spacing of diamond-shaped load plates. This type of load-transfer device can be placed within 6 in. (150 mm) of an intersection (Fig. 3.13). Square and rectangular dowels cushioned on the vertical sides by a compressible material also permit movement parallel and perpendicular to the joint (Fig. 3.14). These types of load-transfer devices are useful in other slab types where the joint should have load-transfer capability while allowing some differential movement in the direction of the joint, such as might be necessary in post-tensioned and shrinkage-compensating concrete slabs or in slabs with two-directional doweling (Schrader 1987). In saw-cut contraction joints, aggregate interlock should not be relied upon for effective load transfer for wheeled traffic if the expected joint width exceeds 0.035 in. (0.9 mm) (Colley and Humphrey 1967).

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.

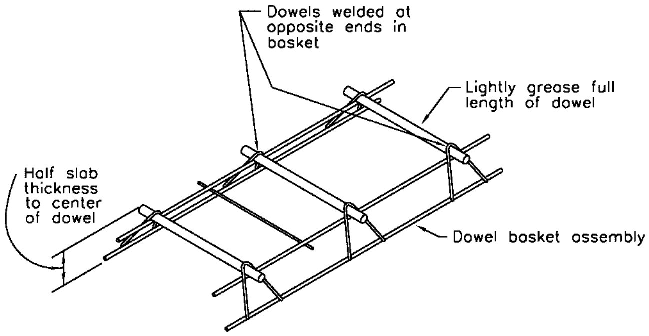


Fig. 3.10—Dowel basket assembly.

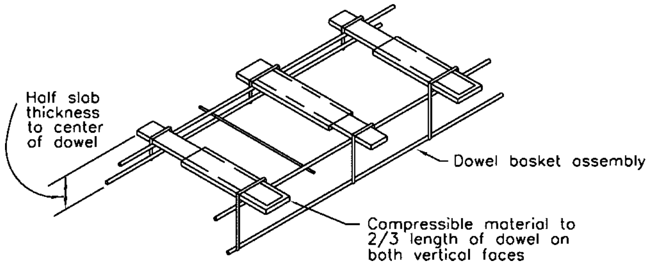


Fig. 3.11—Rectangular load plate basket assembly.

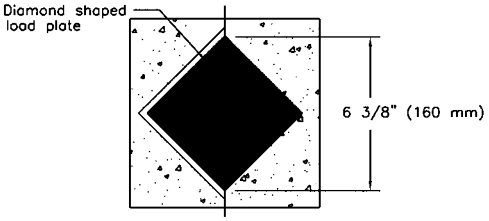


Fig. 3.12—Diamond-shaped load plate at construction joint.

Continuation of a part of the slab reinforcing through contraction joints can provide some load-transfer capability without using dowels but significantly increases the probability of out-of-joint random cracking.

Round, square, and rectangular dowels for slab-on-ground installation should meet ASTM A 36. The diameter or cross-sectional area, length, shape, and specific location of dowels as well as the method of support should be specified by the designer. Refer to Table 3.1 and Fig. 3.9 to 3.14.

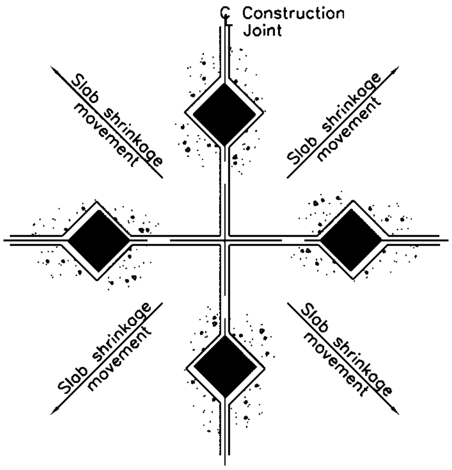


Fig. 3.13—Diamond-shaped load plates at slab corner.

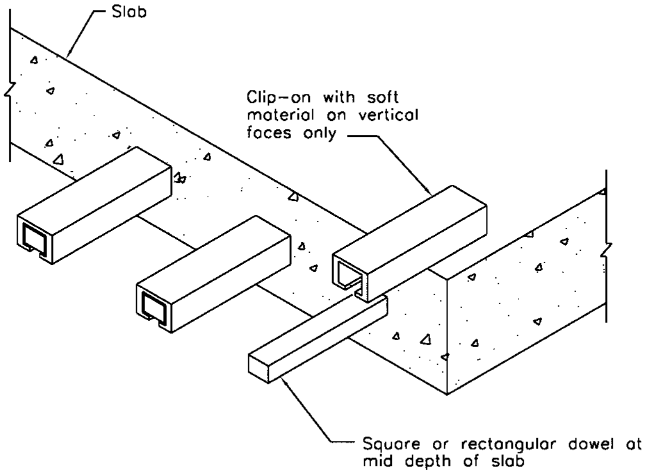


Fig. 3.14—Doweled joint detail for movement parallel and perpendicular to the joint.

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 (PTI 1990; PTI 2000). Where significant slab movement is expected, steel plating of the joint edges is recommended; for strengthening the edges (Fig. 3.15 and 3.16).

A doweled joint detail at a jacking gap in a post-tensioned slab (ASTM 1994; Spears and Panarese 1992) is shown in Fig. 3.16.

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 impact the construction of suspended slabs and should be included in the contract documents prepared by the designer:

- 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; and
- Tolerances (forms, structural steel, reinforcement, and concrete).

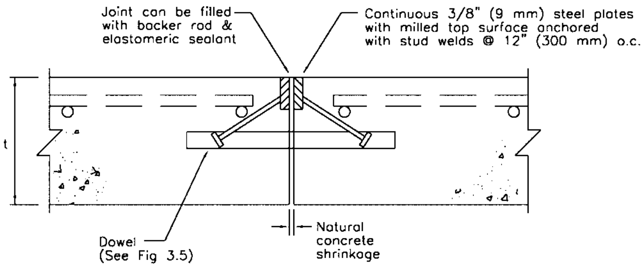


Fig. 3.15—Typical armored construction joint detail.

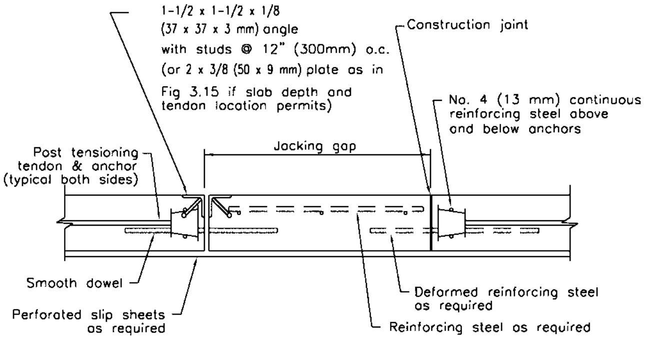


Fig. 3.16—Typical doweled joint detail for post-tensioned slab.

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

1. Cast-in-place suspended floors;
2. Slabs with removable forms;
3. Slabs on metal decking; and
4. 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, Precast/Prestressed Concrete Institute, and tolerances of ACI 117.

The levelness of suspended slabs depends on the accuracy of formwork and strikeoff but is further influenced (especially in the case of slabs on metal decking) by the behavior of the structural frame during and after completion of construction. Each type of structural frame behaves somewhat differently; it is important for the contractor to recognize these differences and plan accordingly.

The presence of camber in some floor members and the ACI 117 limitation on tolerances in slab thickness dictate that concrete be placed at 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 designer. Achieving a level deflected surface can require increasing the slab thickness more than 3/8 in. (9.5 mm) in local areas. The committee recommends that concrete placement procedures and the basis for acceptance of the levelness of a completed concrete floor surface be established and agreed upon by key parties before beginning suspended floor construction (Tipping 1992).

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 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 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 mild steel reinforced floor system 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 designer, an initial required 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.

3.3.4 *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, with a resultant loss of part or all of the desired void space in the vicinity of the form failure. This failure can be instantaneous but can also occur 30 or 45 min after strikeoff. 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 placement of concrete.

3.3.5 *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 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, unless the frame is preloaded to allow deflection to take place before strikeoff, and slab thickness is allowed to vary outside norms dictated by ACI 117. The presence of camber in some floor members and the ACI 117 limitation on variation in slab thickness generally dictates that concrete be placed to a uniform thickness over the supporting steel.

3.3.5.1 *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. 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 designer on the project (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 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 this type of crack should be addressed to the satisfaction of key parties before beginning suspended floor construction.

3.3.5.2 *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.

3.3.6 *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.

3.3.7 *Reinforcement*—For cast-in-place concrete suspended slabs, reinforcing steel location varies as dictated by the contract documents. Post-tensioning reinforcement, when used, is enclosed in a plastic or metal sleeve and is tensioned by a hydraulic jack after the concrete reaches sufficient compressive strength. Elongation and subsequent anchoring of the ends of post-tensioning tendons results in the transfer of compressive force to the concrete (PTI 1990).

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

3.3.8 *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.

3.3.8.1 *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.

3.3.8.2 *Composite slabs on metal deck*—An important consideration when deciding on the location of 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, therefore, deflects less than a noncomposite 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 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.

Following are general guidelines for deciding on the location of construction joints in composite slabs on metal deck:

1. Construction joints that parallel secondary structural steel beams should normally be placed near the midspan of the slab between beams;

2. 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 not be included in the initial placement. It is important to 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; and

3. 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.

3.3.8.3 *Noncomposite slabs on metal deck*—The placement of construction joints in noncomposite slabs on metal deck should follow the same general guidelines discussed for slabs on removable forms in Section 3.3.7.1.

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

3.3.9 *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 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 metal deck is flexible. 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 5.7.3 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 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).

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 approximately 2 in. (50 mm) of concrete cover (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 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 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 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, 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 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 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, thus avoiding 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.

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 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 should not be used (Section 5.7.3). Experience has shown that these snow-melting piping systems 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 on both the 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. If not properly embedded, systems can accelerate deterioration by increasing seepage of salt-water 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.