Guide to Residential Concrete Construction

Reported by ACI Committee 332

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Guide to Residential Concrete Construction

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Guide to Residential Concrete Construction

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This guide provides practical information about the construction of quality residential concrete. It covers concrete work for one- and two-family dwellings with a maximum height of two stories above grade and a basement that is either cast-in-place or placed as precast elements. Information on materials, proportions, production, delivery, and testing is provided. Separate chapters on footings, walls, and slabs provide information on subgrade, forms, reinforcement, placement, consolidation, finishing, and curing. Special considerations regarding insulation and hot and cold weather are included. Common problems and their repair are also addressed. The discussion of specific design provisions and all drawings provided by this guide are intended to offer illustrations of typical practice and should not be interpreted as meeting the requirements of specific codes or project specifications. Applicable codes and construction documents take precedence over the information contained in this document.

Keywords: finish; footing; form; slab; slab-on-ground; subgrade; tolerance; wall.

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CHAPTER 1—INTRODUCTION

Concrete is the most widely used construction material throughout the world. Concrete is used in commercial structures, transportation, water and waste management, public works, farm construction, and utility and residential structures. Based on the amount of concrete produced for each of these categories, residential construction accounts for the second largest application of concrete.

1.1—Scope

This guide provides practical information about the construction of quality residential concrete. It covers concrete work for one- and two-family dwellings with a maximum height of two stories above grade and a basement that is either cast-in-place or placed as precast elements. Information on materials, proportions, production, delivery, and testing is provided. Separate chapters on footings, walls, and slabs provide information on subgrade, forms, reinforcement, placement, consolidation, finishing, and curing. Special considerations regarding insulation and hot and cold weather are included. Common problems and their repair are also addressed. The discussion of specific design provisions and all drawings provided by this guide are intended to offer illustrations of typical practice and should not be interpreted as meeting the requirements of specific codes or project specifications. Applicable codes and construction documents take precedence over the information contained in this document.

Information not presented in this guide includes above-grade concrete walls, deep foundation systems (such as piles, drilled piers, or caissons), free-standing retaining walls (>4 ft [1.2 m]), post-tensioned slabs-on-ground, and elevated concrete slabs. Information on the use of lightweight concrete is not covered in this guide. Guidance is available for these elements in other ACI documents. This guide also does not cover loading and design for seismic forces with the exception of guidance on types of connections between the sill plate and foundation wall commonly used in higher seismic design categories. Additional information on seismic loading and design can be found in the International Residential Code (IRC).

1.2—Definitions

accelerator—see **admixture, accelerating**.

admixture—a material other than water, aggregates, hydraulic cement, and fiber reinforcement; used as an ingredient of a cementitious mixture to modify its freshly mixed, setting, or hardened properties and is added to the batch before or during its mixing.

admixture, accelerating—an admixture that causes an increase in the rate of hydration of the hydraulic cement and thus shortens the time of setting, increases the rate of strength development, or both.

admixture, air-entraining—an admixture that causes the development of a system of microscopic air bubbles in concrete, mortar, or cement paste during mixing, usually to increase its workability and resistance to freezing and thawing.

admixture, retarding—an admixture that causes a decrease in the rate of hydration of the hydraulic cement and lengthens the time of setting.

admixture, water-reducing—an admixture that either increases slump of freshly mixed mortar or concrete without increasing water content or maintains slump with a reduced amount of water, the effect being due to factors other than air entrainment.

admixture, water-reducing (high-range)—a water-reducing admixture capable of producing large water reduction or great flowability without causing undue set retardation or entrainment of air in mortar or concrete.

agent, release—material used to prevent bonding of concrete to a surface.

aggregate—granular material, such as sand, gravel, crushed stone, crushed hydraulic-cement concrete, or iron blast-furnace slag, used with a hydraulic cementing medium to produce either concrete or mortar.

aggregate, coarse—aggregate predominantly retained on the 4.75 mm (No. 4) sieve, or that portion retained on the 4.75 mm (No. 4) sieve.

aggregate, fine—aggregate passing the 9.5 mm (3/8 in.) sieve, almost entirely passing the 4.75 mm (No. 4) sieve, and predominantly retained on the 75 μm (No. 200) sieve; or that portion passing the 4.75 mm (No. 4) sieve and predominantly retained on the 75 μm (No. 200) sieve.

air-entraining agent—see **admixture, air-entraining**.

air entrainment—the incorporation of air in the form of microscopic bubbles (typically smaller than 1 mm) during the mixing of either concrete or mortar.

alkali—salts of alkali metals, principally sodium or potassium; specifically, sodium and potassium occurring in constituents of concrete and mortar, usually expressed in chemical analyses as the oxides Na_2O and K_2O.

alkali-silica reaction—see **reaction, alkali-silica**.

allowable bearing capacity—the maximum pressure to which a soil or other material should be subjected to guard against shear failure or excessive settlement.

anchor bolt—see **bolt, anchor**.

anchor strap—a galvanized light gauge steel device designed to transfer uplift and/or lateral forces from wood framing members to concrete foundations. The device is cast into the concrete foundation wall with attachment points for anchorage of the building deck.

bar—an element, normally composed of steel, with a nominally uniform cross-sectional area used to reinforce concrete.

bar, deformed—a reinforcing bar with a manufactured pattern of surface ridges intended to reduce slip and increase pullout resistance of bars embedded in concrete.

bar diameter—the proper designation of the sizes for reinforcement bars used in concrete construction, expressed as d_b.

bar support—hardware used to support or hold reinforcing bars in proper position to prevent displacement before and during concreting.

barrier, vapor—see **retarder, vapor**.

blast-furnace slag—the nonmetallic product consisting essentially of silicates and aluminosilicates of calcium and other bases that is developed in a molten condition simultaneously with iron in a blast furnace.

bleeding—the autogenous flow of mixing water within, or its emergence from, newly placed concrete or mortar; caused by the settlement of the solid materials within the mass; also called water gain.

blockout—a space within a concrete structure under construction in which fresh concrete is not to be placed.

bolt, anchor—a metal bolt or stud, headed or threaded, that is cast in place, grouted in place, or drilled into finished concrete, and used to hold various structural members or embedments in the concrete, and to resist shear, tension, and vibration loadings from various sources such as wind and machine vibration; also known as a hold-down bolt or a foundation bolt.

boring—a sample of soil or concrete for tests.

calcium chloride—a crystalline solid, $CaCl_2$; in various technical grades, it is used as a drying agent, as an accelerator of concrete, as a deicing chemical, and for other purposes. (See also **admixture, accelerating**.)

cement, blended—a hydraulic cement consisting essentially of an intimate and uniform blend of granulated blast-furnace slag and hydrated lime; or an intimate and uniform blend of portland cement and granulated blast-furnace slag, portland cement and pozzolan, or portland blast-furnace slag cement and pozzolan, produced by intergrinding portland cement clinker with the other materials or by blending portland cement with the other materials, or a combination of intergrinding and blending.

cement, portland—a hydraulic cement produced by pulverizing portland-cement clinker, and usually in combination with calcium sulfate.

cement paste—binder of concrete and mortar consisting essentially of cement, water, hydration products, and any admixtures together with very finely divided materials included in the aggregates.

cementitious—having cementing properties.

chair—see **bar support**.

chute—a sloping trough or tube for conducting concrete, cement, aggregate, or other free-flowing materials from a higher to a lower point.

compound, curing—a liquid that can be applied as a coating to the surface of newly placed concrete to retard the loss of water or, in the case of pigmented compounds, to reflect heat so as to provide an opportunity for the concrete to develop its properties in a favorable temperature and moisture environment.

compressive strength—see **strength, compressive**.

concrete—a composite material that consists essentially of a binding medium within which is embedded particles or fragments of aggregate (usually a combination of fine aggregate and coarse aggregate) in portland-cement concrete; the binder is a mixture of portland cement and water, with or without admixtures.

concrete, ready mixed—concrete manufactured for delivery to a purchaser in a fresh state.

consolidation—the process of inducing a closer arrangement of the solid particles in freshly mixed concrete or mortar during placement by the reduction of voids, usually by vibration, centrifugation, rodding, tamping, or some combination of these actions; also applicable to similar manipulation of other cementitious mixtures, soils, aggregates, or the like.

construction joint—see **joint, construction**.

contraction joint—see **joint, contraction**.

controlled low-strength cementitious material—material that is intended to result in a compressive strength of 1200 psi (8.3 MPa) or less.

cover—in reinforced concrete, the least distance between the surface of embedded reinforcement and the outer surface of the concrete.

creep—time-dependent deformation due to sustained load.

curing—action taken to maintain moisture and temperature conditions in a freshly placed cementitious mixture to allow hydraulic cement hydration and (if applicable) pozzolanic reactions to occur so that the potential properties of the mixture may develop. (See ACI 308R.)

curing compound—see **compound, curing**.

curling—the distortion of an originally (approximately) linear or planar member into a curved shape, such as the warping of a slab to differences in temperature or moisture content in the zones adjacent to its opposite faces.

darby—a hand-manipulated straightedge, usually 3 to 8 ft (1 to 2.5 m) long, used in the early stage of leveling operations of concrete or plaster preceding supplemental floating and finishing.

dead load—see **load, dead**.

deformed bar—see **bar, deformed**.

deformed reinforcement—metal bars, wire, or fabric with a manufactured pattern of surface ridges that provide a locking anchorage with surrounding concrete.

deicer—a chemical, such as sodium or calcium chloride, used to melt ice or snow on slabs and pavements, with such melting being due to depression of the freezing point.

dowel—

1. a steel pin, commonly a plain or coated round steel bar, that extends into adjoining portions of a concrete construction (such as at an expansion or contraction joint in a pavement slab), so as to transfer shear loads; or

2. a deformed reinforcing bar intended to transmit tension, compression, or shear through a construction joint.

dropchute—a device used to confine or to direct the flow of a falling stream of fresh concrete.

1. **dropchute, articulated**—a device consisting of a succession of tapered metal cylinders designed so that the lower end of each cylinder fits into the upper end of the one below; or

2. **dropchute, flexible**—a device consisting of a heavy rubberized canvas or plastic collapsible tube.

durability—the ability of concrete to resist weathering action, chemical attack, abrasion, and other conditions of service.

edging—tooling the edges of a fresh concrete to provide a rounded edge.

elephant trunk—an articulated tube or chute used in concrete placement. (See also **dropchute** and **tremie**.)

engineered fill—material placed into an excavation or onto a subgrade to a desired elevation in consecutive layers, allowing for compaction to a specified density.

fiber reinforcement—slender and elongated filaments in the form of bundles, networks, or strands of any natural or manufactured material that can be distributed throughout freshly mixed concrete.

fill—material placed to bring grade or subgrade to the desired elevation.

finishing—leveling, smoothing, consolidating, and otherwise treating surfaces of fresh or recently placed concrete or mortar to produce desired appearance and service. (See also **float** and **trowel**.)

float—a tool (not a darby), usually of wood, aluminum, or magnesium, used in finishing operations to impart a relatively even but still open texture to an unformed fresh concrete surface. (See also **darby**.)

floating—the operation of finishing a fresh concrete or mortar surface by use of a float; precedes troweling when that is to be the final finish.

flowable fill—a self-consolidating cementitious material used primarily as a backfill in place of compacted fill. Also referred to as controlled low-strength cementitious material (CLSM).

fly ash—the finely divided residue that results from the combustion of ground or powdered coal and that is transported by flue gases from the combustion zone to the particle removal system.

footing—a structural element that transmits loads directly to the soil.

form—a temporary structure or mold for the support of concrete while it is setting and gaining sufficient strength to be self-supporting.

form lining—materials used to line the concreting face of formwork to impart a smooth or patterned finish to the concrete surface, to absorb moisture from the concrete, or to apply a set-retarding chemical to the formed surface.

form tie—see **tie, form**.

Fresno trowel—a thin steel trowel that is rectangular or rectangular with rounded corners, usually 4 to 10 in. (100 to 250 mm) wide and 20 to 36 in. (420 to 900 mm) long, having a 4 to 16 ft (1 to 5 m) long handle, and used to smooth surfaces of nonbleeding concrete and shotcrete.

grade—the prepared surface on which a concrete slab is cast; the process of preparing a plane surface of granular material or soil on which to cast a concrete slab.

heat of hydration—heat evolved by chemical reactions with water, such as that evolved during the setting and hardening of portland cement, or the difference between the heat of solution of dry cement and that of partially hydrated cement.

hydrostatic pressure—the presence of water increasing the pressure applied to a structural element.

insulating concrete form (ICF)—stay-in-place wall form made of foam plastic or other insulation materials that is filled with reinforced concrete. The form remains in place to create fully insulated, reinforced concrete walls used for foundations, basements, and above-grade load-bearing walls.

isolation joint—see **joint, isolation**.

joint—a physical separation in a concrete system, whether precast or cast-in-place; includes intentionally made cracks that occur at specified locations.

joint, construction—the surface where two successive placements of concrete meet, across which it may be desirable to achieve bond and through which reinforcement may be continuous.

joint, contraction—formed, sawed, or tooled groove in a concrete structure that creates a weakened plane to regulate the location of cracking resulting from the dimensional change of different parts of the structure. (See also **joint, isolation**; and **joint, construction**.)

joint, isolation—a separation between adjoining parts of a concrete structure, usually a vertical plane, at a designed location so as to interfere least with the performance of the structure, yet allow relative movement in three directions and avoid formation of cracks elsewhere in the concrete and through which all or part of the bonded reinforcement is interrupted. (See also **joint, contraction;** and **joint, construction**.)

keyway—a recess or groove in one lift or placement of concrete that is filled with concrete of the next lift, giving shear strength to the joint.

licensed design professional—an individual who is registered or licensed to practice the respective design profession as defined by the statutory requirements of the professional registration laws of the state or jurisdiction in which the project is to be constructed.

limestone sweetening—the popular term for replacing approximately 30% of the reactive sand-gravel aggregate with crushed limestone, is effective in controlling deterioration in some sand-gravel aggregate concretes. Refer to AASHTO (2001), Farny and Kosmatka (1997), and PCA (1998) for more information on tests to demonstrate the effectiveness of the above control measures.

live load—see **load, live**.

load, dead—a constant load in structures that is due to the mass of the members, the supported structure, and permanent attachments or accessories.

load, live—any load that is not permanently applied to a structure; transitory load.

moisture resistance—treatment of concrete or mortar to retard the passage or absorption of water or water vapor, either by application of a suitable coating to exposed surfaces, use of a suitable admixture or treated cement, or use of preformed films, such as polyethylene sheets, under slabs-on-ground.

mortar—a mixture of cement paste and fine aggregate; in fresh concrete, the material occupying the interstices among particles of coarse aggregate; in masonry construction, joint mortar may contain masonry cement, or may contain hydraulic cement with lime (and possibly other admixtures) to afford greater plasticity and workability than are attainable with standard portland-cement mortar.

pad footing—an isolated footing or column support that transfers vertical load from the structure above to the soil. Also known as a spread footing.

paste—see **cement paste**.

permeability—the property of a material that determines the rate at which liquids or gases pass through it.

placement—the process of placing and consolidating concrete; a quantity of concrete placed and finished during a continuous operation; inappropriately referred to as pouring.

porosity—the ratio usually expressed as a percentage of the volume of voids in a material to the total volume of the material including the voids.

post-tensioning—a method of prestressing concrete in which tendons are tensioned after the concrete has hardened.

pozzolan—a siliceous or siliceous and aluminous material that in itself possesses little or no cementitious value but that will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds having cementitious properties.

reaction, alkali-silica—the reaction between alkalies (sodium and potassium) in portland cement and certain siliceous rocks or minerals, such as opaline chert, strained quartz, and acidic volcanic glass, present in some aggregates; the products of the reaction may cause abnormal expansion and cracking of concrete in service.

release agent—see **agent, release**.

reinforced concrete—structural concrete reinforced with no less than the minimum amounts of prestressing steel or nonprestressed reinforcement required by ACI 318 or 332.

reinforcement—bars, wires, strands, or other slender members that are embedded in concrete in such a manner that they and the concrete act together in resisting forces.

removable concrete form (RCF)—a removable wall form made of wood, aluminum, steel, or a combination of these materials that is set to the desired wall design and filled with concrete. The forms are then removed to reveal concrete walls used for foundations, basements, and above-grade load-bearing walls.

retarder, vapor—membranes located under concrete floor slabs that are placed on grade to retard transmission of water vapor from the subgrade. Also known as a vapor barrier (refer to Section 5.1.3).

sealer—a liquid that is applied to the surface of hardened concrete to either prevent or decrease the penetration of liquid or gaseous media (for example, water, aggressive solutions, and carbon dioxide) during service exposure that is absorbed by the concrete, is colorless, and leaves little or nothing visible on the surface. (See also **compound, curing**.)

sealing compound—see **sealer**.

segregation—the differential concentration of the components of mixed concrete, aggregate, or the like, resulting in nonuniform proportions in the mass.

self-consolidating concrete (SCC)—also known as self-compacting concrete, SCC is a highly flowable, nonsegregating concrete that can spread into place, fill the formwork, and encapsulate the reinforcement without any mechanical consolidation.

setting time, final—the time required for a freshly mixed cement paste, mortar, or concrete to achieve final set. ASTM C 403 provides the procedure to determine the final set time by plotting penetration resistance until it equals 4000 psi (27.6 MPa).

setting time, initial—the time required for a freshly mixed cement paste, mortar, or concrete to achieve initial set. ASTM C 403 provides the procedure to determine the initial set time by plotting penetration resistance until it equals 500 psi (3.5 MPa).

shore—a temporary support for formwork, fresh concrete, or recently built structures that have not developed full design strength; also called prop, tom, post, and strut.

shrinkage—decrease in either length or volume. Note: shrinkage may be restricted to the effects of moisture content or chemical changes.

slab—a molded layer of plain or reinforced concrete that is flat and horizontal (or nearly so); it is usually of uniform but sometimes of variable thickness, and is either on the ground or supported by beams, columns, walls, or other framework.

slump—a measure of consistency of freshly mixed concrete, mortar, or stucco equal to the subsidence measured to the nearest 1/4 in. (6 mm) of the molded specimen immediately after removal of the slump cone.

soundness—the freedom of a solid from cracks, flaws, fissures, or variations from an accepted standard; in the case of a cement, freedom from excessive volume change after setting; in the case of aggregate, the ability to withstand the aggressive action to which concrete containing it might be exposed, particularly that due to weather.

spread footing—a generally rectangular prism of concrete, larger in lateral dimensions than the column or wall it supports, to distribute the load of a column or wall to the subgrade.

steel fiber—pieces of smooth or deformed cold-drawn wire, smooth or deformed cut sheet, melt-extracted fibers, or other steel fibers that are sufficiently small to be dispersed at random in a concrete mixture.

strength, compressive—the measured maximum resistance of a concrete or mortar specimen to axial compressive loading; expressed as force per unit of cross-sectional area; or the specified resistance used in design calculations.

strength, tensile—maximum unit stress that a material is capable of resisting under axial tensile loading; based on the cross-sectional area of the specimen before loading.

structural slab—concrete element that transfers load to supports through actions of flexure and shear; usually not supported by grade.

subgrade—the soil prepared and compacted to support a structure or pavement system.

sulfate attack—either a chemical reaction, physical reaction, or both between sulfates usually in soil or groundwater and concrete or mortar; the chemical reaction is primarily with calcium aluminate hydrates in the cement-paste matrix, often causing deterioration.

synthetic fiber—a man-made fiber, commonly made of polypropylene, nylon, or polyester.

tensile strength—see **strength, tensile**.

thickened slab—a footing constructed as an integral part of a floor slab.

tie, form—a mechanical connection in tension used to prevent concrete forms from spreading due to the fluid pressure of fresh concrete; also known as a web in ICF systems.

tremie—a pipe or tube through which concrete is deposited under water, having a hopper for filling and a bail for moving the assemblage at its upper end.

trowel—a flat, broad-blade steel hand-tool used in the final stages of finishing operations to impart a relatively smooth surface to concrete floors and other unformed concrete surfaces; also a flat triangular-blade tool used for applying mortar to masonry. (See also **Fresno trowel**.)

troweling—smoothing and compacting the unformed surface of fresh concrete by strokes of a trowel. See also **finishing**.

vapor retarder—see **retarder, vapor**. Also known as vapor barrier (see Section 5.1.3).

viscosity—the property of a material that resists change in the shape or arrangement of its elements during flow, and the measurement thereof.

viscosity-modifying admixture—an admixture that enhances concrete performance by modifying the viscosity and controlling the rheological properties of the concrete mixture. Usually used in conjunction with high-range water-reducing admixtures to produce SCC mixtures.

volume change—an increase or decrease in volume due to any cause.

wall—a vertical element used primarily to enclose or separate spaces.

walls, foundation—structural elements of a foundation that transmit loads to the footing or directly to the subgrade.

walls, moderately reinforced—structural concrete walls reinforced with minimum steel reinforcement that are provided for shrinkage crack control and that satisfy the design requirements for applied load without the need for additional steel reinforcement.

walls, plain reinforced—structural concrete walls with no reinforcement or with less reinforcement than the minimum amount specified for reinforced concrete, or with reinforcement that does not conform to the definition of deformed reinforcement.

walls, reinforced—structural concrete walls reinforced with no less than the minimum amounts of prestressing steel or nonprestressed reinforcement required by ACI 318 or 332.

web—in ICF systems, a mechanical connection in tension used to prevent concrete forms from spreading due to the fluid pressure of fresh concrete; related to form ties used in removable forming systems.

workability—the property of freshly mixed concrete or mortar that determines the ease with which it can be mixed, placed, consolidated, and finished to a homogenous condition.

CHAPTER 2—CONCRETE

2.1—Fundamentals

The main ingredients in concrete are cementitious materials, fine aggregate (sand), coarse aggregate (stone or gravel), and water. Additionally, admixtures are frequently used to alter the performance of the mixture. Ready mixed concrete plants vary the proportions of these ingredients to create concrete with different properties. Increasing the benefit of one property, however, can compromise another area. As an example, the addition of 8 gal. (30 L) of water at the job site to an 8 yd^3 (6 m^3) truckload of freshly mixed concrete will make it easier to place, but it increases the potential to decrease the strength while increasing shrinkage and, therefore, the potential for crack development. When the properties of the concrete mixture need to be adjusted, the concrete supplier should be consulted for a variety of quality-controlled solutions. The final mixture proportions should meet the requirements of ASTM Standards C 94 or C 685, the applicable building code, or the project specifications.

2.1.1 *Material functions*

2.1.1.1 *Aggregates*—Aggregates are the major constituent of concrete, and they influence the properties and performance of both freshly mixed and hardened concrete. Their primary function is to provide volume stability in addition to serving as an inexpensive filler. Chemically stable aggregates in concrete do not react chemically with cement in a harmful manner. A chemical reaction known as alkali-silica reactivity (ASR) can occur between portland-cement concrete and certain aggregates. This can directly cause deterioration of the concrete as well as expediting other reactions that in turn cause damage such as freezing-and-thawing or corrosion-related damage. ASR can be reduced by keeping the concrete as dry as possible, and the reactivity can be virtually stopped if the internal relative humidity of the concrete is kept below 80%. Because this is difficult to achieve, the use of blended cements or supplementary cementitious materials, limestone sweetening, and some chemical admixtures that help control ASR can be beneficial. Aggregates occupy the major portion of concrete by volume and should have certain characteristics of size, shape, surface texture, and geology to produce good concrete. The ideal particle shape is cubical or rounded. Aggregate particles that are cubical or rounded facilitate better flowability and, therefore, lower water-cementitious material ratios (*w/cm*) can be used. The aggregates should be clean and graded, with a uniform distribution of particle sizes ranging from 0.0118 in. (300 μm) to 3/4 or 1 in. (19 or 25 mm) for most residential concrete. Aggregates with high absorption properties may have high shrinkage properties.

2.1.1.2 *Paste*—Cementitious paste is formed by the combination of cementitious materials and water, and has two principle functions:

- To coat and bond the aggregate particles together; and
- To fill the void spaces between the aggregate.

For any combination of materials, the strength of the resulting concrete mixture depends primarily on the *w/cm*. More cementitious materials in the mixture will generally increase the strength. The more water used for a fixed amount of cementitious materials, the higher the *w/cm*, the thinner the paste, and the weaker the concrete. The amount of water in the mixture is also directly proportional to the amount of shrinkage and cracking in the hardened concrete. Cementitious materials are considered to be portland cement and supplementary cementitious materials, such as fly ash, slag, and silica fume, blended or added separately at the batch plant.

2.1.2 *Plastic concrete*—Characteristics of plastic concrete are important to those who place and finish it. Properly proportioned concrete should be workable during placement and finishing. Additional characteristics that impact the final hardened concrete structure serviceability include consistency, setting time, and bleeding.

2.1.2.1 *Slump*—Consistency of concrete is a measure of the flowability of the mixture. Flowability of plastic concrete is more commonly called slump. A slump test (ASTM C 143) measures the consistency of the concrete for slumps up to 8 in. (200 mm), and a modified slump-flow test (ASTM C 1611) for self-consolidating concrete (SCC) measures a mixture with greater fluidity. The slump test is performed by filling a truncated cone (Fig. 2.1) with concrete and measuring how much the concrete subsides, or slumps, when the cone is lifted. A higher slump of 6 to 8 in. (150 to 200 mm) (Fig. 2.2) indicates that the concrete is more workable than a lower slump of 1 to 3 in. (25 to 75 mm) (Fig. 2.3). Lower-slump concrete is stiffer and more difficult to consolidate and finish. High slumps, if achieved by only adding water, will result in lower strengths and greater shrinkage characteristics of the concrete if the total amount of water added exceeds the maximum *w/cm* designed for the mixture. The modified slump-flow test is a procedure used to determine the fluidity or filling ability characteristics of SCC in the absence of obstructions (Fig. 2.4) and is measured in terms of the amount of spread the mixture achieves. The normal spread for SCC is 18 to 32 in. (460 to 810 mm). The inverted slump-cone procedure (ASTM C 995) can be a better indicator to determine the workability for fiber-reinforced concrete than the usual slump cone procedure (ASTM C 143). Fiber-reinforced concrete is placed by vibration because it can exhibit very low slump due to the presence of the fibers. Because it can be easily consolidated, the inverted slump-cone procedure is recommended. Slump can also be increased by the use of chemical admixtures (water-reducing agents) with few negative effects on the concrete properties.

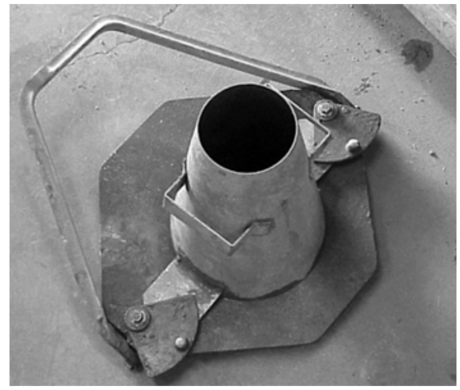

Fig. 2.1—Truncated cone for slump tests.

Fig. 2.2—Slump test for consistency of concrete illustrating a high slump.

Fig. 2.3—Slump test for consistency of concrete illustrating a very low slump.

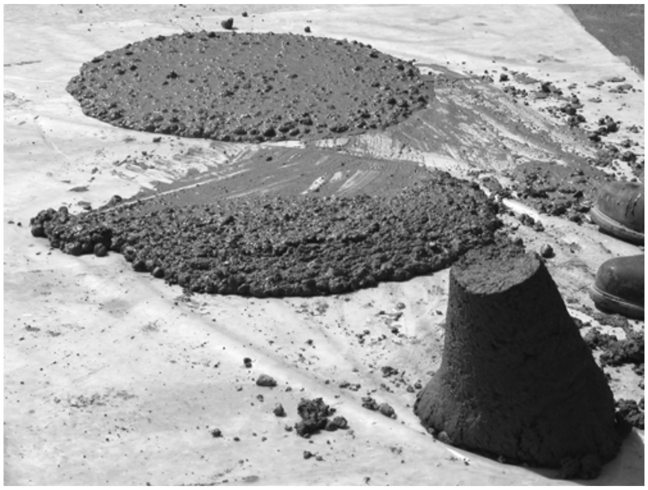

Fig. 2.4—Modified slump test for measuring flowability of self-consolidating concrete (SCC).

Fig. 2.5—Cylinder loaded vertically until failure.

2.1.2.2 *Setting time*—Setting time of concrete is the time between the first addition of water and the initial stiffening of the concrete. The initial set of concrete, as measured by ASTM C 403, may range from 4 to 8 hours, depending on cement properties and type, mixture proportions, ambient temperature, and mixture temperature. If the temperature of a concrete mixture is reduced from 70 to 55 °F (21 to 13 ºC), the setting time can increase to about 10 hours. Conversely, if this mixture is placed at 90 °F (32 ºC), the setting time decreases to about 4 hours. As the concrete temperature drops below 40 ºF (4 ºC), the maturity or strength gain can slow until it reaches between 14 and 27 °F (–10 and –3 °C), when it will cease. The concrete will resume its maturation process when the concrete temperature climbs again above this range. Concrete that reaches a freezing temperature where maturity stops before reaching a compressive strength of 500 psi (3.5 MPa) (Section 2.1.3.1) may be permanently damaged and can suffer significant ultimate strength reduction. Concrete that has attained a compressive strength of 500 psi (3.5 MPa) will not be damaged by exposure to a single freezing cycle. After reaching 500 psi (3.5 MPa), concrete will mature to its potential strength without adverse affects despite subsequent exposure to cold weather. Planning for these severe cold conditions to protect the concrete from freezing until this point may include a combination of modifications to the mixture proportion, placement temperatures and practices, insulating products, and supplemental heat, depending on the anticipated baseline temperatures.

2.1.2.3 *Bleeding*—Excess water rises to the surface after concrete is placed and before initial set, while all of the solid materials settle. This is known as bleeding. Often, this bleed water forms a sheen on the surface of the concrete. Bleed water that is mixed into the surface during finishing produces a weakened zone under the finished surface. This is the cause of surface defects like crazing, dusting, or scaling in concrete slabs. Finishing operations should not be conducted while bleed water is present (Section 5.4.5). Special precautions need to be taken during ambient conditions of rapid evaporation. Evaporation retardants may be an aid during these conditions.

2.1.3 *Hardened concrete*—Concrete for residential construction involves a balance between reasonable economy and the requirements for workability, finishing, durability, strength, and appearance. The required characteristics are governed by the intended use of the concrete, the conditions expected to be encountered at the time of placement, and the environmental factors affecting the use of the product. Compressive and tensile strengths, volume stability, and durability are all parameters that affect the service life of hardened concrete.

2.1.3.1 *Compressive strength*—The compressive strength of concrete at 28 days is specified in the design documents. Concrete suppliers can provide a report that will document the strength characteristics of the supplied mixture from previous testing. Alternatively, this strength can be determined by an ACI Certified Field Testing Technician Grade I, casting and curing 4 in. (100 mm) diameter by 8 in. (200 mm) high cylinders or 6 in. (150 mm) diameter by 12 in. (300 mm) high cylinders on the job site in accordance with ASTM C 31 and testing them by an accredited laboratory in a compression testing machine (Fig. 2.5) in accordance with ASTM C 39. This strength is expressed in pounds per square inch (psi) or megapascals (MPa). Minimum recommended compressive strength requirements for residential applications are shown in Table 2.1. More information on compressive strength of concrete can be found in NRMCA CIP 35.

2.1.3.2 *Tensile (flexural) strength*—The tensile (flexural) strength of concrete is typically 8 to 15% of its compressive strength. Table 2.1 shows the recommended compressive strengths for residential concrete. The minimum tensile (flexural) strength correlation is shown as modulus of rupture (MOR), expressed as a coefficient multiplied by the square root of the compressive strength, $\sqrt{f'_c}$. Using an assumed coefficient of 7 for 2500, 3000, 3500, and 4000 psi concrete results in a minimum MOR of 350, 383, 414, and 443 psi, respectively. Tensile strength is an important characteristic for residential concrete because it provides resistance to cracking from drying and temperature changes. More information on tensile strength of concrete can be found in NRMCA CIP 16.

Table 2.1—Minimum compressive strength f'_c at 28 days and maximum slump of concrete

Type or location of concrete construction	Weathering probability*			Maximum slump, in. (mm)†
	Negligible f'_c, psi (MPa)	Moderate f'_c, psi (MPa)	Severe f'_c, psi (MPa)	
Type 1: Walls and foundations not exposed to weather. Interior slabs-on-ground, not including garage floor slabs	2500 (17)	2500 (17)	2500 (17)‡	6 (150)
Type 2: Walls, foundations, and other concrete work exposed to weather, except as noted below	2500 (17)	3000 (21)	3000 (21)	6 (150)
Type 3: Driveways, curbs, walkways, patios, porches, steps, and stairs exposed to weather and garage floors, slabs	2500 (17)	3500 (24)	4500 (31)	5 (125)

*Exposure class can be determined by the weather probability map in Fig. 2.7.
†Slumps greater than shown can be achieved by the use of a mid-range or high-range water-reducing admixture.
‡Concrete in these elements that will be subject to freezing and thawing while under construction should be air entrained.

Table 2.2—Air content for Types 2 and 3 concrete under moderate or severe weathering probability

Nominal maximum aggregate size, in. (mm)	Air content, % (tolerance ±1.5%)	
	Moderate	Severe
3/8 (10)	6	7.5
1/2 (13)	5.5	7
3/4 (19)	5	7
1 (25)	4.5	6
1-1/2 (38)	4.5	5

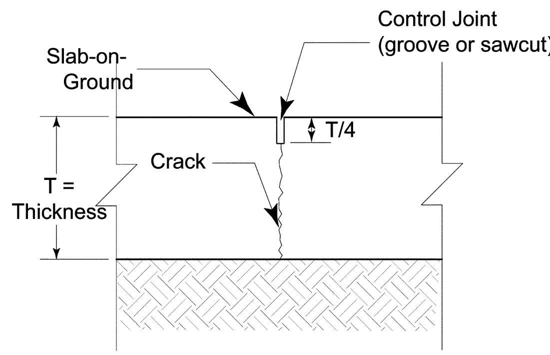

Fig. 2.6—Groove joint for crack control.

2.1.3.3 *Concrete shrinkage*—Concrete shrinkage is a characteristic of concrete that occurs when hardened concrete dries. Much of it takes place at an early age when the concrete is weakest. A 100 ft (30 m) strip of uncured, fresh concrete after 1 year of normal drying will shrink approximately 3/4 in. (19 mm). In reality, however, drying shrinkage is an inherent, unavoidable property of concrete, and shrinkage cracks occur when shrinkage is restrained. Drying shrinkage is always greater near the surface of the concrete, which can result in surface cracking. Other sources of restraint are reinforcing steel embedded in the concrete, the interconnected parts of a concrete structure, the friction of the subgrade on which it is placed, and other obstructions. Cracks will result whenever the tensile capacity exceeds the tensile strength. Fluctuations in temperature can cause tensile stresses associated with thermal contraction when concrete cools, particularly at early stages, can cause cracks.

2.1.4 *Joints*—Using concrete joints is the most effective method of controlling cracking. Concrete that is not properly divided into smaller sections by joints to accommodate drying shrinkage and temperature contraction will crack in a random manner. Control joints are grooved, formed, or sawed into the concrete to provide predetermined locations for the concrete to crack due to the shrinkage stresses. Figure 2.6 shows a grooved joint in a driveway slab. Isolation joints separate a slab from other parts of a structure and permit horizontal and vertical movements of the slab. Joints are described in detail in the chapters on walls and slabs. More information on joints in concrete slabs-on-ground can be found in NRMCA CIP 6.

2.1.5 *Air entrainment*—The use of entrained air in a concrete mixture affects both the plastic and hardened characteristics. A chemical admixture is added by the concrete producer to deliberately entrain many small, closely spaced air bubbles. These air bubbles act like ball bearings in the plastic concrete to improve workability and reduce the amount of water required for a given consistency. This reduces the water demand and the amount of bleed water. Once concrete hardens, these bubbles remain as discreet voids. This air-void system acts as a pressure-relief mechanism and can protect the concrete from the effect of water expanding as it freezes. Any concrete that will be subjected to freezing and thawing should contain entrained air for improved durability. Generally, the amount of entrained air by volume is between 5 and 8%. Specific amounts of air entrainment that should be considered for residential applications are listed in Table 2.2.

2.2—Materials

In addition to the four basic materials that comprise typical concrete mixtures, other widely used materials include chemical admixtures, supplementary cementitious materials, and fibers.

2.2.1 *Cement*—ASTM C 150 defines five types of portland cement, but only four are typically used in residential construction. Type I is a general purpose cement; Type II is a cement that provides moderate protection against sulfate attack; Type III is high-early-strength cement that is sometimes used to achieve faster setting and increased early strengths; and Type V is a cement that is used where severe exposure to sulfates is anticipated. Blended cement, defined by ASTM C 595, and hydraulic cement, defined by ASTM C 1157, are occasionally used in residential construction. Blended cements consist of preblended combinations of portland cement and supplementary cementitious materials.

2.2.2 *Fine aggregate (sand)*—ASTM C 33 sets limits for fine aggregates on impurities (organic materials, clay, and others) and soundness, as well as establishing gradation requirements.

2.2.3 *Coarse aggregate (gravel or crushed stone)*—The applicable standard for coarse aggregates is ASTM C 33. Some aggregates react chemically with the alkali hydroxides in cementitious paste or other sources. These alkali-aggregate problems occur, or a potential risk exists, in nearly all states, especially where silica aggregate is used. Avoiding aggregates that contain reactive minerals or rocks is not an economical option in many regions. The service record of an aggregate source is extremely useful in determining whether a potential problem exists. Where alkali-aggregate potential is known or the performance history of the aggregate indicates the aggregate is harmful, the coarse aggregate should be tested periodically, as determined by the owner, by the aggregate producer to avoid the risk of ASR problems. A petrographic examination, according to ASTM C 295, is useful in determining its potential for causing deleterious reactions in concrete and for planning remedial procedures. The aggregate petrographic examination should identify any potentially reactive constituents and estimate their amount. Some state departments of transportation (DOTs) have found that 80% of their aggregates are reactive, while other states have very little reactivity, especially if they use limestone. Under certain conditions, when mixtures include these aggregates, low-alkali cements, ASTM C 150 portland cements, supplementary cementitious materials, or a combination of these things should be used to mitigate any deleterious reaction. ASTM C 1260 and C 295 can be used to identify and confirm the existence of nonreactive aggregate. ASTM C 1567 or C 1293 can be used to optimize the amount of supplementary cementitious materials to control ASR.

Aggregates can have other harmful substances that can affect the setting characteristics, cause deterioration, affect bond, increase the water requirements, affect durability, cause stains and popouts, affect workability, and cause abnormal expansion and cracking. A discussion of most of these issues can be found in Section 6.7.

2.2.4 *Water*—The applicable standard for water used in mixing concrete is ASTM C 1602. Recycled water meeting this standard is commonly used. Suitability is determined through a performance-based process that determines if the water and the contained amounts of oils, acids, alkalies, salt, organic materials, or other substances may be deleterious to concrete or reinforcement.

2.2.5 *Chemical admixtures*—A variety of chemical admixtures are used to modify the characteristics of concrete because many of them, such as retarders, accelerators, high-range water-reducing admixtures (HRWRAs), and air-entraining agents affect the placing and finishing characteristics of the concrete. The finishing contractor should be informed of the benefits of chemical admixtures and when their use has been planned by the concrete supplier. More information about chemical admixtures can be found in NRMCA CIP 15.

2.2.5.1 *Air-entraining agents*—Air-entraining agents may be used to provide air entrainment (Section 2.1.5). The applicable standard for air-entraining agents is ASTM C 260.

2.2.5.2 *Normal water reducers*—Normal water reducers lower the amount of water required for a given slump. The applicable standard for normal water reducers is ASTM C 494, Type A.

2.2.5.3 *Retarding water reducers*—Retarding water reducers extend the setting time in addition to reducing water requirements. These admixtures are normally used in hot weather. The applicable standard for retarding water reducers is ASTM C 494, Type D.

2.2.5.4 *Mid-range water reducers*—Mid-range water-reducing admixtures provide moderate water reduction without significantly delaying the setting characteristics of the concrete. These admixtures provide more water reduction than normal water reducers (5.0%), but less water reduction than HRWRAs (12%). This typically results in concrete with a slump range of 5 to 8 in. (125 to 200 mm), and may entrain additional air. Presently, there is not an ASTM standard for these materials. These admixtures are commonly used in residential concrete; refer to industry publications on the subject.

2.2.5.5 *High-range water-reducing admixtures (superplasticizers)*—HRWRAs produce higher water reductions than normal water reducers. The applicable standard for HRWRAs is ASTM C 494, Type F (for normal setting) or Type G (for retarded set).

2.2.5.6 *Plasticizers*—Plasticizers are chemical admixtures that, when added to concrete, produce flowing concrete without further addition of water. These admixtures are not required to provide water reduction. The applicable standard for plasticizing admixtures is ASTM C 1017, Type I (plasticizing) and Type II (plasticizing and retarding).

2.2.5.7 *Viscosity-modifying admixtures*—Viscosity-modifying admixtures are chemical admixtures that, when added to concrete, enhance the viscosity of the mixture, thus reducing aggregate segregation, settlement, and bleeding. These materials are used primarily with HRWRAs and supplementary cementitious materials to produce SCC mixtures. More information on SCC can be found in NRMCA CIP 37.

2.2.5.8 *Accelerating water reducers*—Accelerating water reducers reduce set time in addition to reducing water requirements. These admixtures are normally used in cold weather. The applicable standard for accelerating water reducers is ASTM C 494, Type E.

2.2.5.9 *Accelerators*—Calcium chloride is the most effective and commonly used accelerator in residential concrete. The amount used should not exceed 2% by weight of cementitious materials in unreinforced concrete. For concrete with conventional reinforcement, the amount of $CaCl_2$ should not exceed 0.30%, or 0.06% by weight of cementitious materials in concrete with prestressed reinforcement. Some specifications for prestressed concrete prohibit the use of calcium chloride due to the potential for corrosion problems with prestressing steel. Calcium chloride should not be used when dissimilar metals are embedded in concrete. Nonchloride accelerating admixtures are available for use in concrete. These nonchloride accelerators are effective for set acceleration and strength development; however, the degree of effectiveness of some of these admixtures is dependent on the ambient temperature at the time of placement. The applicable standard for accelerating admixtures is ASTM C 494, Type C.

2.2.6 *Supplementary cementitious materials*—Natural pozzolans (ASTM C 618, Class N), fly ashes (ASTM C 618, Class C or F), slags (primarily ground-granulated blast-furnace slag [GGBFS]—ASTM C 989, Grades 80, 100, and 120), silica fume (ASTM C 1240), rice-husk ash, and metakaolin are some of the materials known as supplementary cementitious materials. The benefits derived from the use of supplementary cementitious materials include functional or engineering benefits and ecological benefits. Some of the engineering benefits are improved workability, ultimate strength enhancement, durability to withstand chemical attack, improved resistance to thermal cracking due to lower heat of hydration, and increased tensile strain capacity. Additionally, ecological benefits are realized by putting the positive benefits of these by-products to use into the manufacture of blended cements and concrete products rather than disposing of them. NRMCA CIP 30 provides further reference for supplementary cementitious materials.

2.2.7 *Fibers*

2.2.7.1 *Synthetic fibers*—Synthetic fibers are man-made fibers manufactured by the petrochemical and textile industries. The largest use of synthetic fibers (acrylic, aramid, carbon, nylon, polyester, polyethylene, and polypropylene) is in flat-slab construction, to control bleeding and plastic shrinkage cracking. Further discussion of the benefits of synthetic fibers can be found in ACI 544.1R. The applicable standards for the use of synthetic fibers are found in ASTM C 1116 and C 1299. More information on synthetic fibers can be found in NRMCA CIP 24.

2.2.7.2 *Steel fibers*—The largest use of steel fibers in concrete is in flat slabs-on-ground that are subject to high loads and impact. Steel fibers have also been used for shotcrete applications. Further discussion of the benefits of steel fibers can be found in ACI 544.1R. The applicable standard and classification for steel fibers is found in ASTM A 820.

2.2.8 *Mineral pigments*—Mineral pigments meeting ASTM C 979 requirements can be added to color the concrete.

2.3—Mixture proportioning

The preceding section addressed the importance of using quality materials in concrete. These materials should be combined in proper proportions to ensure success. To establish these proportions, consideration should be given to: *w/cm*, durability, workability, strength, placing and finishing, drying shrinkage, economy, and aesthetics.

2.3.1 *Water-cementitious material ratio*—The *w/cm* is determined by dividing the weight of water by the weight of cementitious materials used in the mixture. Cementitious materials include cement plus the supplementary cementitious materials (generally fly ash and slag) used in the concrete. Concrete strength, resistance to water penetration, and resistance to freezing-and-thawing damage all increase with a reduction in the *w/cm*. Adding water to a concrete mixture, all other things being equal, will make it more workable, but will decrease its strength and durability.

2.3.2 *Freezing-and-thawing durability*—In areas where freezing and thawing occur, the durability of exterior concrete is always a concern. The use of air-entrained concrete will dramatically improve the durability of concrete exposed to moisture during cycles of freezing and thawing. Air-entrained concrete will improve concrete's resistance to surface scaling caused by chemical deicers. The amount of air entrainment is specified as a percentage of the total volume of concrete, and varies with the maximum size of coarse aggregate used. Table 2.2 provides guidelines for the proper amount of air entrainment for various coarse aggregate sizes and exposures. The need for adequate curing of the concrete cannot be overemphasized. Curing has a strong influence on the properties of hardened concrete such as durability, strength, watertightness, abrasion resistance, volume stability, resistance to freezing and thawing, and resistance to deicer salts.

In general, concrete slabs-on-ground should have minimum concrete compressive strengths of 3500 psi (24 MPa) at 28 days for moderate freezing-and-thawing exposure, and 4500 psi (31 MPa) for severe freezing-and-thawing exposure (Table 2.1). For such conditions, the slump should be as low as practical, with a maximum of 5 in. (130 mm).

Deicing chemicals can pose a severe durability problem for residential concrete. If exposure to deicing chemicals is anticipated, concrete should be properly finished and cured, and a drying period should be provided prior to exposure to salts and freezing temperatures. Air drying removes excess moisture from the concrete that in turn reduces the internal stress caused by freezing-and-thawing conditions and deicing chemicals. Concrete slabs should receive at least 30 days of air-drying time after the moist-curing period and before exposure to deicing chemicals. The exact length of time for air drying will vary with climate and weather conditions. The application of deicing chemicals should be avoided during the first winter following placement.

2.3.3 *Sulfate attack*—Concrete that will be exposed to elevated levels of water-soluble sulfates should be proportioned to provide adequate sulfate resistance as determined and specified by a licensed design professional. ACI 201.2R provides guidelines to control sulfate attack.

2.3.4 *Alkali-silica reactivity (ASR)*—A reaction is produced where aggregates with siliceous components (opaline chert, strained quartz, and acidic volcanic glass) are used in combination with cementitious materials containing high alkalis (sodium and potassium). This reaction expands with constant exposure to water, such as in exterior concrete. When this expansion occurs, the concrete deteriorates, breaking the concrete near the expanded piece of aggregate. Alkali reactivity is reduced with a lower internal concrete relative humidity, and the reactivity can be virtually stopped if the internal relative humidity of the concrete is kept below 80%. Because this is difficult to achieve, beneficial actions include the use of a low-alkali cement (ASTM C 150 portland cements), the use of blended cements or supplementary cementitious materials, limiting the alkali content of the

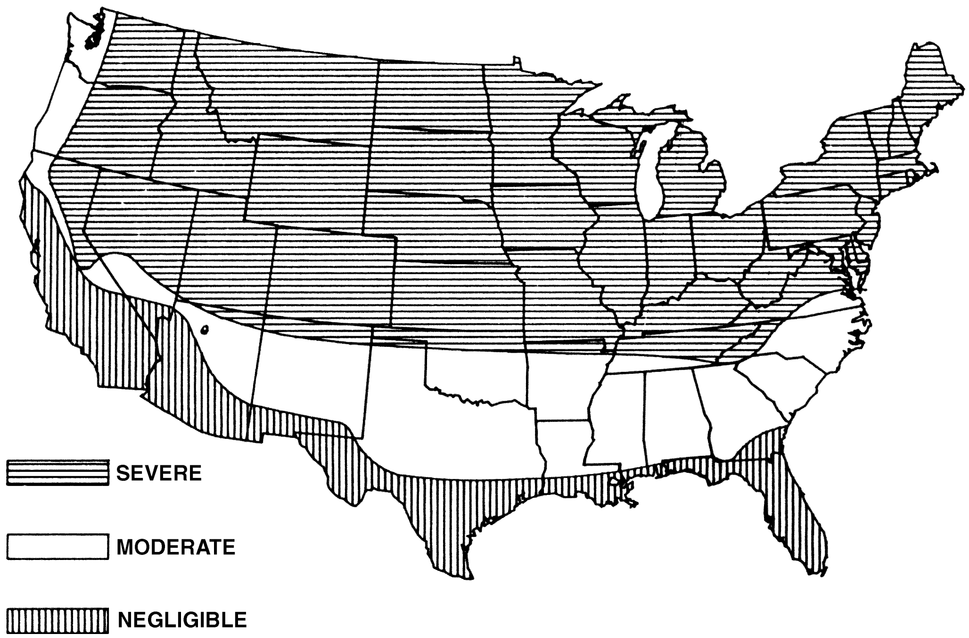

Fig. 2.7—Weathering probability map for concrete.

concrete, limestone sweetening, and the use of suitable chemical admixtures. ACI 221.1R cites ASTM C 441 as the test method that evaluates the effectiveness of a supplementary cementitious material in reducing expansions due to ASR. ASTM C 311 provides a procedure for evaluating the effectiveness of supplementary cementitious materials in reducing ASR expansion that is a modification of ASTM C 441. ASTM C 1260 and C 295 can be used to identify and confirm the existence of nonreactive aggregate. ASTM C 1567 or C 1293 can be used to optimize the amount of supplementary cementitious materials to control ASR. For further information on this subject, a review of ACI 221.1R is recommended.

2.3.5 *Strength and slump*—The required strength for residential concrete is largely determined by its required durability. Table 2.1 gives guidelines for minimum specified strengths and recommended slumps for various types of construction in different weathering conditions (Fig. 2.7).

2.4—Ordering

Ready-mixed concrete producers supply concrete for the vast majority of residential construction. Concrete is a perishable material, and most specifications limit the time between the initial addition of water and final placement to 90 min. Careful planning for good access to the forms and timely delivery and placement are important in achieving the desired results. Alternatively, a proper concrete mixture proportion and the use of admixtures can extend the time allowed for final placement.

To avoid yield discrepancies, the user needs to understand that the volume of hardened concrete may be, or appears to be, less than expected due to waste and spillage, over-excavation, spreading forms, some loss of entrained air, or settlement of wet mixtures, none of which are the responsibility of the producer. NRMCA provides some guidelines on discrepancies in yield in CIP 8. When placing an order for concrete, a number of items need to be considered. The volume of the concrete, expressed in cubic yards (cubic meters), should be calculated by the contractor and provided to the concrete producer. The strength of the concrete, type of cement, desired slump, maximum size of coarse aggregate, and the use of chemical admixtures and supplementary cementitious materials, or both, should be agreed upon. The order should give the time of the first load and, if required, the time between loads. Any special requirements for the concrete, such as chemical admixtures or fiber reinforcement, should be noted when the order is placed. Day-to-day variations in materials; placing, finishing, and curing techniques; and weather conditions can produce variations in the color of the finished concrete. Although these variations may not affect the performance of the concrete, they may be aesthetically undesirable. Before a coloring agent is used on a project, a mock-up section is suggested so that all parties are in agreement as to the acceptable color, texture, and overall appearance of the concrete. NRMCA provides guidelines on ordering concrete in CIP 31.

2.5—Production and delivery

Ready-mixed concrete suppliers are typically responsible for the proportioning, batching, mixing, and delivery of the concrete. After mixture proportions are established, the individual materials should be weighed within tolerances and mixed before placement according to ASTM C 94. Before discharge, a one-time addition of water to the concrete (to increase slump) at the job site is permitted provided that the intended *w/cm* is not exceeded. The amount of added water should be documented. If the addition exceeds the maximum water permitted in the mixture proportions, it may have an undesirable effect on the concrete properties, including reduced strength and durability.

2.6—Testing

Although field testing of concrete is not normally performed on residential work, to assure mixture performance, proper testing should be conducted by the producer to verify the consistency of the concrete supplied on a frequent basis. On small residential projects, it would be impractical to provide testing on every project, but past experience and sound judgment should be relied upon in evaluating the concrete being delivered. On large residential projects, it is recommended to use an accredited testing laboratory to sample and test the concrete. Proper testing of concrete on larger projects can reduce the cost associated with troubleshooting problems should they occur. Testing should be done by a certified ACI Concrete Field Testing Technician, Grade I or equivalent.

CHAPTER 3—FOOTINGS

This chapter provides discussion and guidelines for the design and construction of footings for residential structures no more than two stories in height. In keeping with the scope of this document and the provisions of ACI 332, deep footings, such as caissons or piles, and footing designs based on increased load factors for seismic regions are not included. In such conditions, engineering analysis should be performed.

3.1—Purpose

There are two primary purposes for footings as described in this section. They primarily function to distribute vertical structural loads to the ground from the structure above while anchoring the foundation wall at the lower end against the lateral pressures of the retained soils. Continuous footings also serve an important function during construction, as they provide a level and consistent support for setting the wall forms and establishing tolerance control.

3.1.1 *Transfer of loads to soil*—Distribution of the loads over an expanded area will decrease the soil-bearing pressure and therefore reduce the possibility of settlement. Excessive differential settlement, occurring when portions of a structure significantly settle at rates different than adjacent portions, can result in cracks in foundation walls, frame walls, or ceilings, and can cause doors and windows to bind. Footing width is an important characteristic to prevent this occurrence.

The width of the footing is often determined by the thickness of the wall it supports. Conditions may exist, however, where loads exceed the commonly tabulated residential loads as described in the *International Residential Code* (IRC) or ACI 332 or where soil-bearing capacity is less than anticipated. These conditions can be addressed by increasing the width of the footing, which results in a larger area for distribution of the loads.

3.1.2 *Construction platform*—The thickness of a foundation wall may be sufficient for the soil-bearing capacity to transfer building loads to the soil in residential structures where soil conditions are good (usually 2000 lb/ft^2 [96 KPa] and higher soil bearing). A footing, however, is also typically used to provide a platform on which to construct the foundation wall (Fig. 3.1). Four inches (100 mm) on both sides of the proposed wall is a typically sufficient width to set the wall forms. Footings for this purpose are described in 3.4.1 and 3.4.2. Requirements for the width and depth are found in ACI 332 and the IRC.

Fig. 3.1—Forms setting on footing.

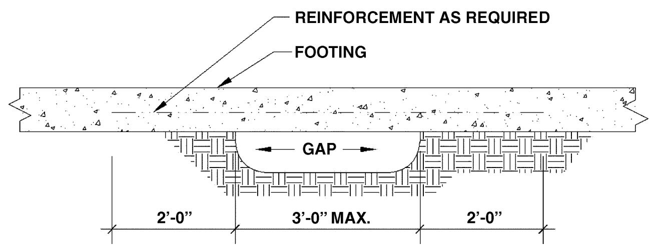

Fig. 3.2—Footing spanning gap.

3.2—Excavation

This section provides guidance for the excavation of the subgrade in preparation for the placement or forming of footings.

3.2.1 *Depth*—The depth of the bottom of the footing should extend below the frost line for a particular location or otherwise be frost-protected. Local building code officials should be able to establish the prevailing frost depth for a given area. Footing excavations should be carried no deeper than the anticipated bearing elevation of the footing. If footings are excavated deeper than the proposed depth, they should either be filled with concrete or engineered fill. If there is a short soft area or an area where a trench extends under a footing, the gap can be bridged with reinforcement placed in the footing (Fig. 3.2). Reinforcing for these conditions should be performed as required in ACI 332.

3.2.2 *Width*—The width of a footing excavation is not important if the entire footing will be formed above the bearing elevation of the footing or if the purpose of the footing is only as a forming platform for the walls. If the earth is used as part or all of the side form, the width should be within the tolerances listed in this document.

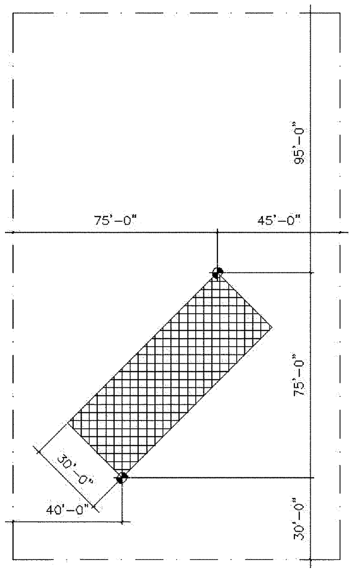

Fig. 3.3—Typical boring locations.

3.3—Soil

Determining the performance of the subgrade may be one of the most important characteristics of the project. This section discusses the issues related to making these determinations and what impacts they have on the performance of the residential foundation.

3.3.1 *Soil testing*—Soil borings for a site may be necessary to determine the subgrade content of the soil. Differential strata like sands, clays, silts, and other features that are not visible from the surface can impact the ability of the soil to carry the loads applied through the foundations, resulting in differential settlement. If soil testing is required, at least two borings should be ordered for a typical residence (1600 ft^2 [150 m^2] or less). Three or more may be required for larger structures or structures with special loading or site conditions. The test locations should be selected near opposite ends of the structure at the locations of bearing walls or, alternately, at an exterior bearing wall and at the location of an anticipated point load (Fig. 3.3). Boring depths should be at least 5 ft (1.5 m) below the anticipated depth of the bottom of the footing. This will identify any abnormal conditions that might be just below the level of the excavation.

The soil report should identify the soil type(s) encountered and the depths of each type. The bearing capacity of each type of soil should also be estimated. Soil reports typically contain disclaimers indicating that the representations in the report cover only soil at the locations and depths ordered. For this reason, a project engineer and soil engineer should select boring locations and depths carefully.

3.3.2 *Soil-bearing pressure*—Model building codes provide prescriptive soil-bearing values that are to be used unless a detailed soil investigation is performed. Local and public records may provide data about soil type. If the soil type can be ascertained, soil-bearing capacity can be determined from sources such as Table 3.1, which provides common soil-bearing capacities and related characteristics. If there is any question or doubt regarding the soil capacity, a soil investigation should be performed by a licensed geotechnical engineer.

3.3.3 *Fill*—Placing fill below footings should be avoided when possible. It is difficult to judge the quality of fill and to obtain proper compaction with the equipment and testing that is available on most residential job sites. If fill is unavoidable, it should be granular fill (sand, lime, or gravel) compacted to the specified bearing capacity. Controlled low-strength materials (CLSM), or flowable fill, can be used as an alternative to granular fill. ACI 229R can be referenced for guidance on the specific aspects of CLSM.

3.3.4 *Water and deposits*—It is recommended not to cast footings in standing water, on mud, on saturated or loose soils, or on materials that have been washed into the footing excavation. Standing water in footing excavations should be removed by draining or pumping, and the soil should be firm before casting. Concrete can be used to displace water from the footing area if it can be accomplished without the water mixing with the concrete.

Soils entering the excavation from either erosion or a cave-in of the sidewall are typically of a different consistency and type than those at the bottom of the excavation. They have also been loosened or disturbed, and will demonstrate different bearing properties than the undisturbed soils at the bottom of the excavation. Any soil deposited in the excavation by water or from the sidewalls of the excavation should be removed before casting the footing. Moist soils typically do not present a problem as long as they are firm.

3.3.5 *Frost/frozen ground*—During cold weather conditions, it is important to protect the excavation from freezing before and after placing concrete. Protection is commonly provided using straw, mineral wool, polystyrene sheets, blanket or batt insulation, or polyethylene films. ACI 306R discusses additional ways to protect the ground from freezing conditions as well as the merits of different systems. Footing substrates where the ground is frozen should be heated. Alternatively, it can be excavated to remove the frozen soil and replaced with engineered fill or the footing depth increased to accommodate the additional excavation.

When shallow frost depths with frozen ground not exceeding 2 in. (50 mm) in depth is encountered, the heat of hydration generated by concrete with a deliver temperature of at least 50 °F (10 °C) is sufficient to raise the temperature of the ground and thaw out the frost penetration. Unless prohibited by code or construction documents, footings may be cast on these conditions as long as the footing is covered immediately after placement to capture the heat from the curing concrete.

3.4—Footing types

Footing types fall into two classifications: continuous footings and pad footings.

3.4.1 *Continuous footings*—Continuous footings (also known as strip footings) extend the length of the supported wall plus a short distance beyond the supported edge. The width of the footing will also extend, beyond both sides of the foundation wall, a dimension that should not exceed the footing thickness. A footing thickness of 8 to 10 in. (200 to

Table 3.1—Soil-bearing capacities

Soil symbols	Description	Maximum bearing capacity, lb/ft^2 (kN/m^2)	Drainage	Frost-heave potential	Expansion potential
BR	Bedrock	30,000 (1436)	Poor	Low	Low
		Clean gravels			
GW	Well-graded gravel sand mixtures, little or no sands	8000 (383)	Good	Low	Low
GP	Poorly graded gravels or gravel-sand mixtures, little or no fines	6000 (287)	Good	Low	Low
		Gravels with fines			
GM	Silty gravels, gravel-sand-silt mixtures	4000 (192)	Good	Medium	Low
GC	Clayey gravels, gravel-clay-sand mixtures	3500 (168)	Medium	Medium	Low
		Clean sand			
SW	Well-graded sands, gravelly sands, little or no fines	5000 (239)	Good	Low	Low
SP	Poorly graded sands or gravelly sand, little or no fines	4000 (192)	Good	Low	Low
		Sand with fines			
SM	Silty sand, sand-silt mixtures	3500 (168)	Good	Medium	Low
SC	Clayey sands, sand-clay mixture	3000 (144)	Medium	Medium	Low
		Fine-grained silts			
ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slight plasticity	2000 (96)	Medium	High	Low
MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	1500 (72)	Poor	High	Low
		Clays			
CL	Inorganic clays of low to medium plasticity, gravelly, sandy, silty, or lean clays	2000 (96)	Medium	Medium	Medium
CH	Inorganic clays of high plasticity, fat clays	1500 (72)	Poor	Medium	High
		Organic (remove organic soil)			
OL	Organic silts and organic silty clays	400 (19)	Poor	Medium	Medium
OH	Organic clays of medium to high plasticity	0	Unsuitable	High	High
PT	Peat and other organic soils	0	Unsuitable	Medium	High

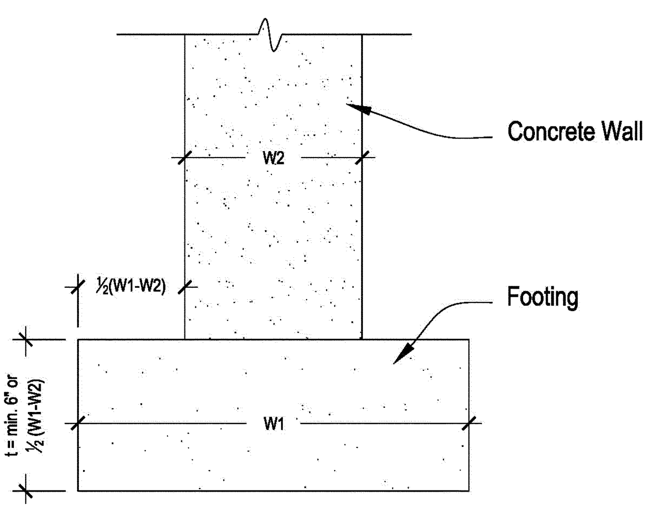

Fig. 3.4—Unreinforced footing.

Fig. 3.5—Reinforced footing.

250 mm) is typical for residences. When continuous footings extend beyond the edge of the wall in dimensions greater than the footing thickness, transverse reinforcing may be required (refer to Fig. 3.4 and 3.5 for unreinforced and reinforced spread footings, respectively), and a licensed design professional should be consulted.

3.4.2 *Pad footing*—A pad footing (Fig. 3.6), also known as a spread footing, is typically used to transfer concentrated loads from a point or concentrated load, such as in a column or pier, to the soil. In some instances, a pad footing may be integrally cast with a continuous footing at locations where a beam bears on a wall and creates a higher concentrated load, particularly when the wall supporting the beam is considered very short (under 4 ft [1.2 m] high). The width and depth of spread (or pad) footings are determined by the load transmitted through them and the soil-bearing capacity.

3.4.3 *Thickened slab*—The concrete slab may be thickened along one edge (continuous footing) or at some point in the middle of the slab (continuous or pad footing). This condition is often used to support a bearing wall in the interior of the

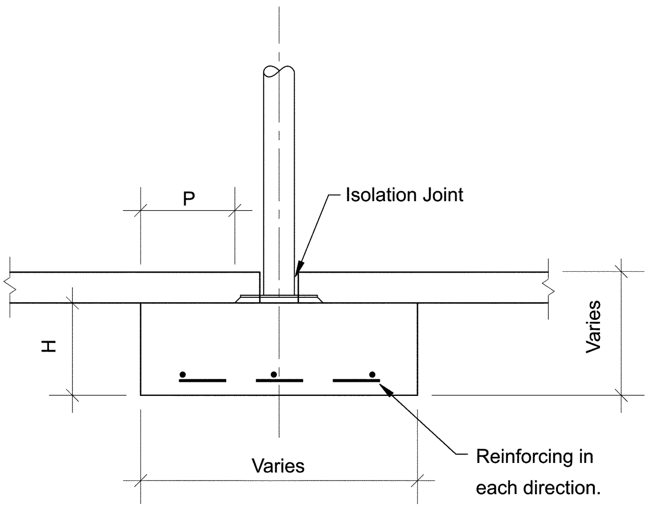

Fig. 3.6—Pad footing.

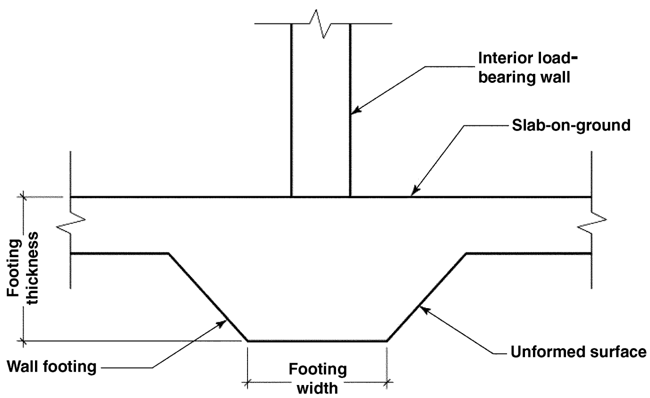

Fig. 3.7—Thickened slab.

building as well as an alternative for supporting columns. This condition is referred to as a thickened slab because it is often placed integrally with the floor slab (Fig. 3.7); it may also be referred to as a shovel footing.

3.5—Footing loads

Footing loads fall into two primary categories: vertical loads and lateral loads.

3.5.1 *Vertical loads*—Vertical loads are classified in two broad categories: dead loads and live loads. Dead loads typically include the weight of the structure, including footings and foundation walls, floor material loads, wall loads, and roof material loads. Live loads include transient loads, such as occupants, furniture, and so on, that are not permanently attached to the structure. Live loads can typically be obtained from the IRC, ACI 332, or the applicable model building codes.

3.5.2 *Lateral loads*—Lateral loads are horizontal forces that are applied in a direction perpendicular or parallel to the plane of the vertical wall and consist primarily of wind loads and soil pressure. Wind can produce loads either parallel or perpendicular to the plane of the wall. Soil pressures produce loads perpendicular to the plane of the wall. Wind loads are typically not a consideration in residential footing design, except locally at embedded hardware, such as holddowns and straps. Uplift on a carport or open porch areas where

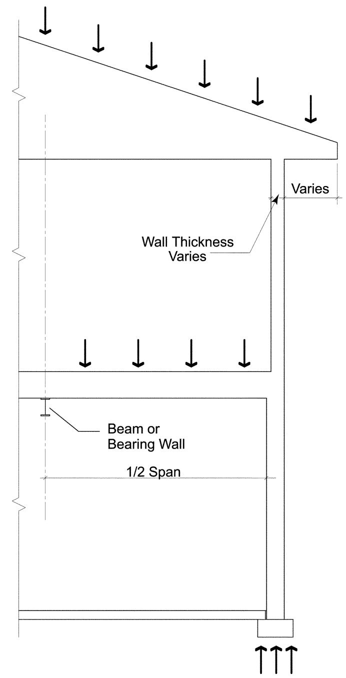

Fig. 3.8—Load diagram.

hurricane or other severe wind conditions are encountered (exclusive of tornadoes) should be designed by a licensed design professional unless local codes address these conditions. Lateral loads on walls supported by footings result in horizontal forces on the footings. These horizontal forces are normally resisted, with adequate factors of safety, by an interior concrete basement slab at the base of the wall (if one is present), friction between the bottom of the footing and the soil, passive soil pressure on the vertical surfaces of the footing, keyways, dowels, or some combination of these. Resistance to displacement produced by unusually large lateral loads should be evaluated by a licensed design professional.

3.5.3 *Load determination*—Figure 3.8 and 3.9 show the process for determining continuous and concentrated loading conditions for a typical residential wall. The calculations illustrate how to determine the cumulative loads applied to the footing through the foundation wall. These loads are then used to determine the required width of footing for a given soil-bearing capacity from design tables such as those found in Tables 3.1 and 3.2.

Vertical concentrated gravity loads placed on a foundation wall may be considered to distribute linearly, following a 1:1 distribution slope. The load can then be evenly distributed along the footing below for a maximum length of twice the dimension *h,* measured from the point where the load is applied to the wall to the bottom of the footing. Load distribution may be carried around corners and nonlinear wall segments. Loads applied to a wall within a distance *h* of an opening or wall termination may only be distributed for a calculated distance along the footing equal to the dimension *h* + (the distance from the load to the opening), unless further analysis is performed. If the pressure caused by the concentrated load, added to the dead plus live load pressures, exceeds the allowable soil-bearing capacity, a wider footing

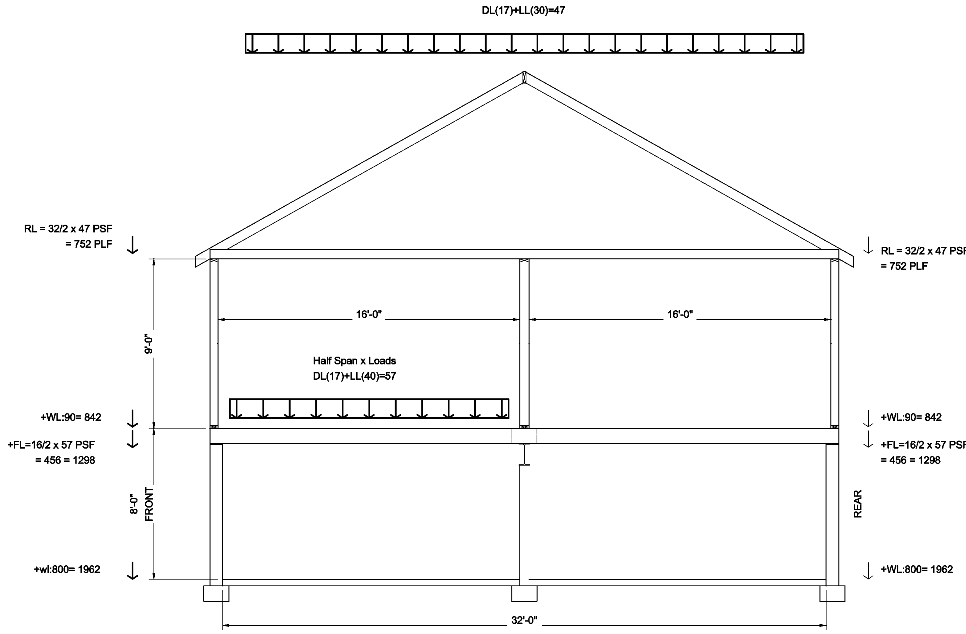

Fig. 3.9—Example calculation.

will be required. When the applied load exceeds a base of 4000 lb (1800 kg) for walls 8 ft (2.4 m) or taller, it is common to increase the footing width in increments of 3 in. (75 mm) for every 5000 lb (2300 kg) of applied load. In walls that are between 4 and 8 ft (1.2 and 2.4 m) tall, these applied loads should be factored by 0.5.

Concentrated loads applied to thickened slabs or spread footings may be considered to be loaded evenly over the area of the footing when loaded concentrically on the footing. The size of the footing is determined by limiting the applied soil pressure (the applied load divided by the plan area of the footing) to the allowable soil-bearing capacity.

3.6—Tolerances

3.6.1 *General*—Some deviation from design documents is afforded in all phases of construction, including concrete. Allowable tolerances are site-specific. For example, a site change in footing elevation of 2 ft (0.6 m) or more due to site conditions is not uncommon. A variation in footing width of 1 in. (25 mm) will have a minimal effect on load transfer capability. Footings may also be deeper than the specified thickness if the footing bears on a suitable soil. In general, however, the footing should be considered within tolerance if the following conditions are met:

- The deviations do not cause the structure to be structurally unstable;
- The deviations do not encroach on areas reserved for other work;
- The deviations do not impede other trades from doing their work; and
- The deviations do not place the structure out of compliance with governing codes.

3.6.2 *Common deviations*—The following tolerances may be used as a guide for footing construction. The use of a plus (+) with the tolerance indicates a limit in the allowable increase to the amount or dimension to which it applies or raises a deviation

Table 3.2—Minimum width *W* of concrete footings for walls, in. (mm)

	Load-bearing value of soil, lb/ft^2 (kN/m^2)					
	1500 (72)	2000 (96)	2500 (120)	3000 (144)	3500 (168)	4000 (192)
Conventional wood frame construction						
One-story	16 (410)	12 (300)	10 (250)	8 (200)	7 (180)	6 (150)
Two-story	19 (480)	15 (380)	12 (300)	10 (250)	8 (200)	7 (180)
Three-story	22 (560)	17 (430)	14 (360)	11 (280)	10 (250)	9 (230)
4 in. (100 mm) brick veneer over wood frame or 8 in. (200 mm) hollow concrete masonry						
One-story	19 (480)	15 (380)	12 (300)	10 (250)	8 (200)	7 (180)
Two-story	25 (640)	19 (480)	15 (380)	13 (330)	11 (280)	10 (250)
Three-story	31 (790)	23 (580)	19 (480)	16 (410)	13 (330)	12 (300)
8 in. (200 mm) solid or fully grouted masonry or insulated concrete forms						
One-story	22 (560)	17 (430)	13 (330)	11 (280)	10 (250)	9 (230)
Two-story	31 (790)	23 (580)	19 (480)	16 (410)	13 (330)	12 (300)
Three-story	40 (1020)	30 (760)	24 (610)	20 (510)	17 (430)	15 (380)

Note: Wall construction shown is for exterior walls above grade. Dimensions provided based on maximum story height of 10 ft (3 m).

from level, while a minus (–) indicates a limit in the allowable decrease. Where only one signed tolerance is specified (+ or –), there is no limit in the opposing direction.

Elevation (deviation from benchmark) .... ±2 in. (50 mm)
Width (deviation from design width)..........–1/2 in. (13 mm)
Thickness (deviation from design thickness [Fig. 3.10]) .....–5%
Levelness (deviation from top of footing)
.... +1/2 in. (13 mm), –2 in. (50 mm)
Slope of subgrade
(slope of soil, bottom of the footing) .... 10% maximum

Additional guidance on tolerances for concrete elements for residential construction can be found in ACI 117.

3.7—Form types

The types of forming systems available for footings include wood, metals, plastic, and fabric, as well as the

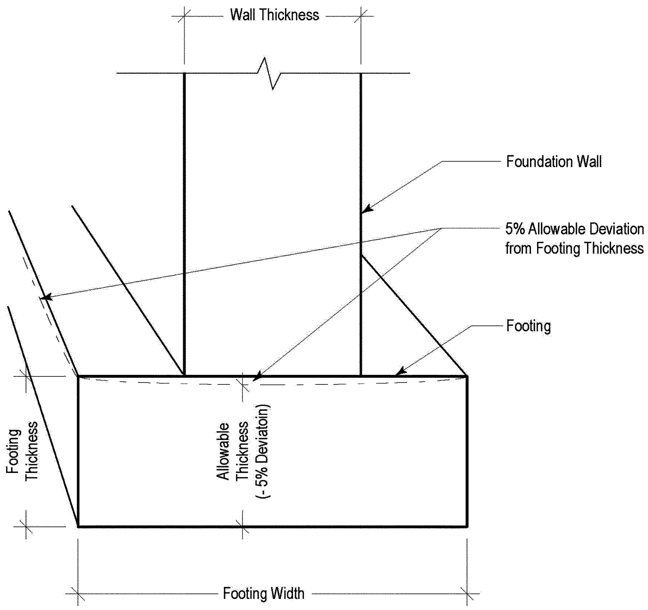

Fig. 3.10—Typical deviation of footing thickness.

Fig. 3.11—Footing formed with wood using full-height side forms.

Fig. 3.12—Aluminum footing form system.

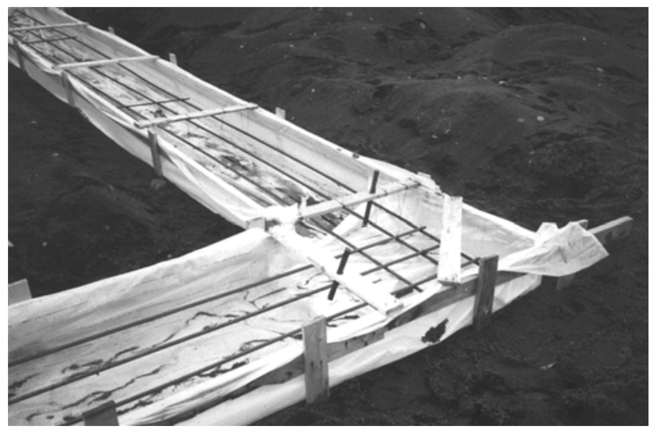

Fig. 3.13—Footing reinforcement placed in fabric forming system.

excavated subgrade. ACI 347 and ACI SP-4 (Hurd 2005) can provide guidance for the selection of forming systems and the specific requirements for each type.

3.7.1 *Wood*—Wood is the most common forming material for footings. Standard-dimension lumber can be used several times before being replaced. Where soil conditions permit, two-by-fours are used to form the top of the footing. The ground is then excavated from the area between the forms until the correct footing depth is reached. If the soil is not self-supporting, side forms should be full height (Fig. 3.11).

3.7.2 *Metal*—Steel or aluminum (Fig. 3.12) is used by some contractors instead of wood because of its durability and rigidity. Metal channels and tubing are the most common shapes. Loops or slots for installing steel stakes are incorporated into the forms. Aluminum that has not been treated or properly cured for use in forming concrete will produce a reaction with the alkali resulting in a damaged finished surface. These forms can be chemically treated or cured through a minimum of two contacts with concrete placements to prevent the affected surface conditions.

3.7.3 *Alternative products*—Manufactured forming systems made of metal fabrics, synthetic fabrics (Fig. 3.13), or plastic are available. Some of the systems are left in place and incorporate the foundation drainage into the form system as shown in Fig. 3.14.

3.7.4 *Free formed*—Footings can be placed without the use of forms (Fig. 3.15) by excavating a trench in the subgrade sufficient to maintain the desired shape during placement or by the use of low-slump concrete. In these conditions, the concrete is placed in the location of the footing and is screeded to the desired level.

3.7.5 *Removal*—Forms can be removed when the concrete is self-supporting or has attained a strength of 500 psi (3.4 MPa).

3.8—Geometry

3.8.1 *Width*—Footings are typically constructed 8 in. (200 mm) wider than the wall thickness (4 in. [100 mm] per side) to provide an adequate platform for setting the wall forms. If soil-bearing capacity is poor (less than 1500 lb/ft^2 [72 kPa]) or loads are high, a wider footing may be required to transfer structure loading to the soil. If a wider footing is

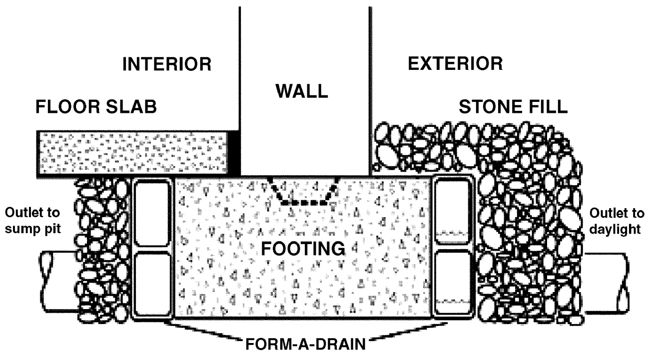

Fig. 3.14—Drawing of drainage provided by plastic system.

Fig. 3.15—Concrete placed into a free formed footing excavation.

required to transfer the load, and the footing extension beyond the face of the supporting wall exceeds the depth of the footing, transverse reinforcement may be required. A licensed design professional should be consulted to determine the specifics of transverse reinforcement in the footings.

If the judgments of the contractor, licensed design professional, and building official the building loads and soil conditions do not require a detailed soil investigation, minimum widths and depths can be set based on prevailing construction practices for the area. Table 3.2 provides values for the minimum width of footings as required by the IRC.

3.8.2 *Thickness*—A footing thickness of 8 or 10 in. (200 or 250 mm) is generally adequate. IRC 2000 allows 6 in. (150 mm) thick footings as well. The wall and the footing provide sufficient strength in most circumstances to span any soft areas in the soil.

3.8.3 *Steps*—Where the bottom elevation of a foundation wall steps (Fig. 3.16), the wall footing does not step, but is terminated at both sides of the elevation change. In this condition, the wall becomes a beam to tie the two footings together and transfer loads to the wall footings on either side. Footing steps may be required to support changes in the bottom elevation of the wall when soil conditions are poor (that is, a continuous footing is required).

Steps that occur in insulated concrete form (ICF) systems should be planned at intervals based on the height of the ICF units to save labor and material costs.

Fig. 3.16—Foundation wall step.

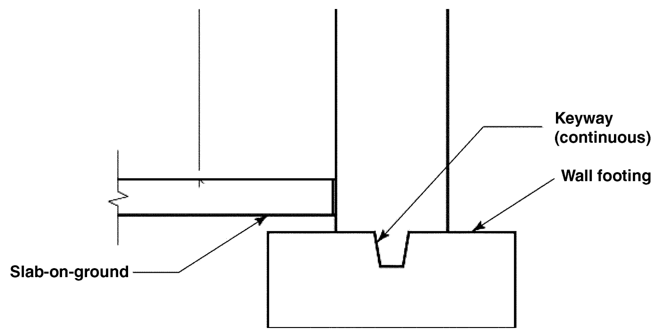

Fig. 3.17—Keyway detail.

Fig. 3.18—Footing with formed keyway.

3.8.4 *Keyways*—Keyways (Fig. 3.17 and 3.18) are used to resist lateral load at the bottom of the wall. They are critical if the backfilling operation begins before placement of the slab. Once in place, the interior slab is sufficient to prevent movement of the wall.

Keyways may be formed using a reverse bevel-cut two-by-four or by removing material from the center of the

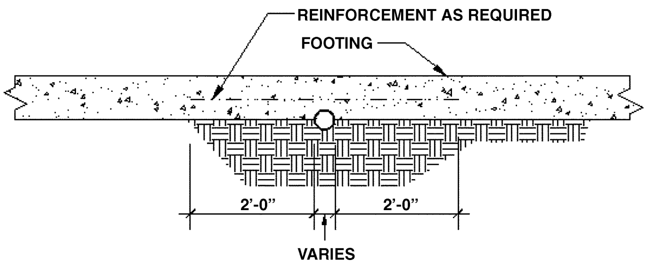

Fig. 3.19—Penetration and reinforcement.

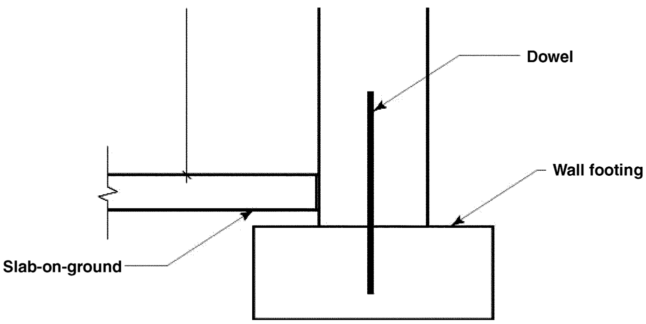

Fig. 3.20—Steel dowel shear connection.

Fig. 3.21—Footing with dowels.

footing after it has been cast but before initial set. The area removed for a keyway should be in the center of the proposed wall location, and should be approximately 1 in. (25 mm) deep by 1 to 1-1/2 in. (25 to 38 mm) wide. A roughened top surface (deformations in excess of 1/8 in. [3.2 mm]) in the area where the wall will be located can also provide sufficient shear transfer if approved by a licensed design professional.

3.8.5 *Penetrations*—Penetrations through footings (Fig. 3.19) should be reinforced with longitudinal reinforcement extending 24 in. (610 mm) on both sides of the penetration. ACI 332, Section 6.2.4.1, provides that footings spanning trenches or penetrations below the footing are to be reinforced with bars extending 24 in. (610 mm) beyond the edges of the span up to 36 in. (910 mm) in length. The design of footings spanning trenches wider than 36 in. (910 mm) should be reviewed by a licensed design professional. Penetrations may also interrupt the continuity of the footing. The foundation wall for these conditions should be reinforced to span the discontinuity with a minimum of two No. 4 (No. 13) reinforcing bars extending as described previously.

3.8.6 *Dowels*—Steel dowels extending from the footing into the wall are an alternative to keyways for shear transfer (Fig. 3.20 and 3.21). A minimum dowel design should include No. 4 (No. 13) reinforcing bars spaced at 24 in. (610 mm) on-center. The dowels should extend at least 12 in. (300 mm) above the top of the footing, and 6 in. (150 mm) into the footing. If the depth of the footing is not adequate to develop a straight bar into the footing, the bottom of the dowels can be hooked. Unless prohibited by local code, the dowels may be pushed into the fresh concrete (also referred to as wet setting of dowel) immediately following striking the final level or they may be positioned in the footing form by driving them into the subgrade before concrete placement to maintain their vertical and horizontal positions as well as alignment.

3.9—Concrete

3.9.1 *Strength*—The minimum compressive strength of concrete specified in ACI 332 and the general building code for footings is 2500 psi (17 MPa) at 28 days. Higher-strength mixtures may be required in poor soils where transverse reinforcing is required.

3.9.2 *Slump*—Slump for concrete used in footings should not exceed 6 in. (150 mm). Concrete containing a HRWRA may be used to increase the slump to a maximum of 8 in. (200 mm). A higher slump is desirable for improved workability, and especially for more effective placement operations with pumps. Caution, however, should be used with higher slumps because segregation is possible and can result in honeycombing and weakened zones that may require costly repair or removal and replacement.

3.10—Reinforcement

3.10.1 *Purpose*—Steel reinforcement in footings consists of reinforcing bars placed longitudinally, transversely, or both, to the direction of the footing. Longitudinal reinforcing is sometimes used to bridge soft spots and minor trenches or to increase strength over narrow excavations (Fig. 3.8). Transverse footing reinforcement is typically not required unless one or more of the following conditions exist: the soil-bearing capacity is poor, wall loads are high, or it is specified by the licensed design professional. Footings can contain reinforcement whether designed as plain concrete members or reinforced concrete members. Provisions for the design of footings can be found in chapter 6 of ACI 332.

3.10.2 *Grade and size*—Grade 40 and 60 (Grade 280 and 420) deformed steel bars are the most commonly used. No. 4 and 5 (No. 13 and 16) bars are the sizes commonly used.

3.10.3 *Placement and cover*—Transverse or longitudinal reinforcing bars should be located near the center of the footing thickness with a minimum cover of 3 in. (76 mm) to the bottom and sides. They can be set on chairs, construction bricks, or other support devices. They may also be positioned by working the reinforcement bars immediately into the fresh concrete placement (known as floating) provided that there will be no vibrating. Bars should be overlapped by a minimum of $30d_b$ (Fig. 3.22).

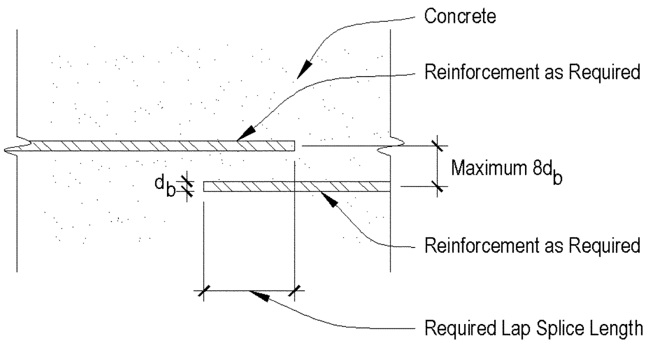

Fig. 3.22—Lap splice requirements for footing and foundation wall reinforcement.

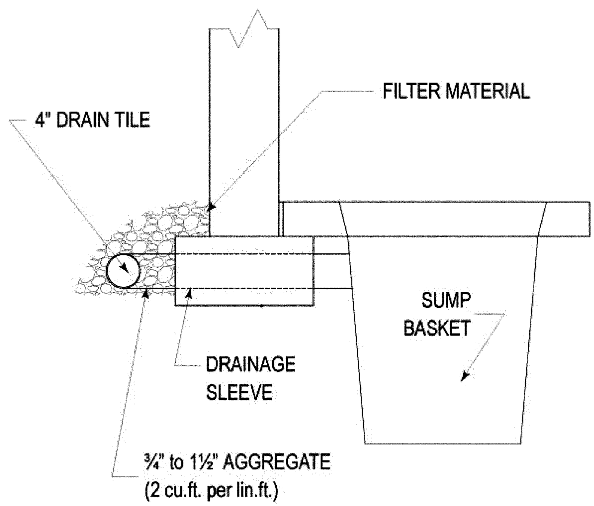

Fig. 3.23—Drain tile system: exterior to pit.

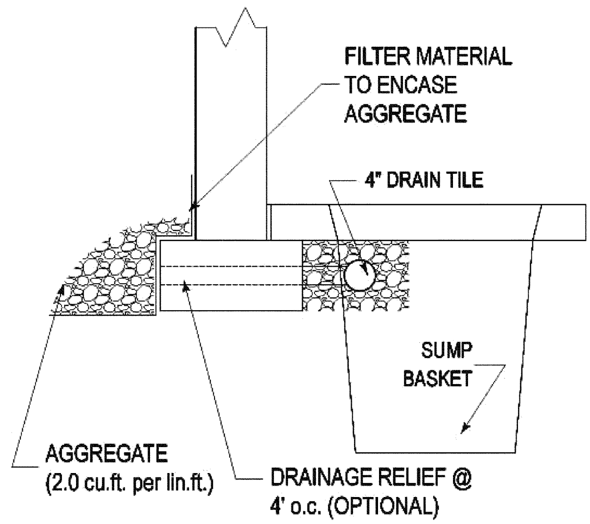

Fig. 3.24—Drain tile system: interior to pit.

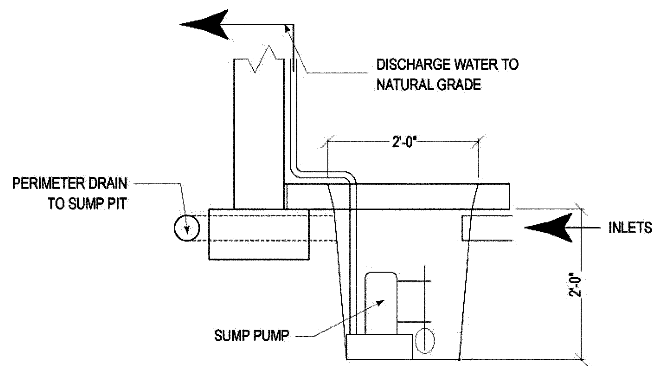

Fig. 3.25—Drain tile system: interior to exterior.

3.11—Placement

3.11.1 *Preparation*—Footings should be formed on firm undisturbed soil, engineered fill, or coarse gravel. Standing water, mud, frozen ground, and other debris should be removed before placement. Up to 1 in. (25 mm) of standing water may be displaced by the concrete if it does not mix with the water. Removal of inappropriate materials below the designed bottom of the footing is required to develop a sound subgrade base for the footing. The overexcavation can be filled with engineered fill or concrete.

3.11.2 *Concrete placement*—Placement of concrete for footings can be by any conventional method, including direct chute, wheelbarrows, crane, pump, or conveyor.

3.12—Curing and protection

3.12.1 *Freezing*—Footings should be protected from freezing until the concrete has attained a compressive strength of 500 psi (3.5 MPa). Additional protection beyond this initial stage should be considered as recommended by ACI 306R based on the intended loading during these conditions.

3.12.2 *Drying*—If the footings will be exposed to excessive drying conditions, such as wind and sun, they should be protected with polyethylene or another form of moisture retarder.

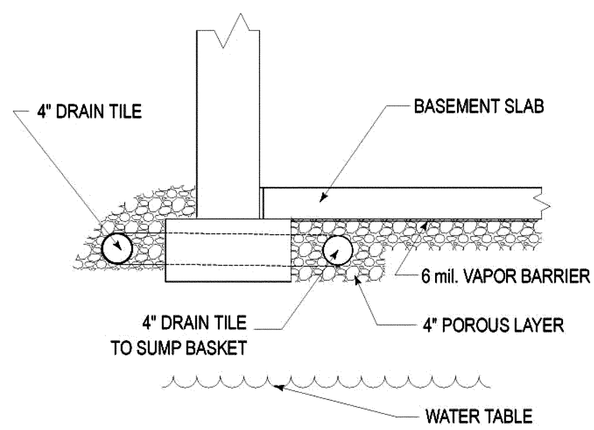

Fig. 3.26—Drain tile system: interior/exterior to pit.

Refer to ACI 308R for specific procedures and recommendations for curing.

3.13—Footing drainage

The footing drainage system is an important part integral to the success of the foundation system. It collects water that drains from the soil, thereby reducing lateral pressure on the wall, and reduces the chances of water penetration through cracks or the footing-wall intersection.

3.13.1 *Footing drains*—Footing drains should be installed at all footings adjacent to interior living or storage space unless the soil is a naturally well-drained soil.

Footing drains may be integral with the footing or be made of slotted PVC drain pipe or clay pipe. The top of the drain system should be placed at or below the top of the interior slab. It should be placed as level as possible. The system should be covered with gravel and covered with filter paper.

The drain tile should be drained to a sump pump, storm sewer, or to daylight in accordance with local building code requirements. Refer to Fig. 3.23 through 3.26 for typical details.

CHAPTER 4—WALLS

The following guidelines are only applicable for wall construction of residential structures with a maximum height of two stories above grade and a basement. Additional requirements on the use and application of these guidelines may be governed by project specifications, local codes, or soil conditions. The foundation walls described are designed as simply supported retaining walls with lateral support at the top and bottom of the walls or free-standing (cantilevered) retaining walls up to 4 ft (1.2 m) in height.

Walls should be designed according to the prescriptive provisions of ACI 332, the IRC, or the applicable general building code. Walls may also be designed according to the design provisions of ACI 332 or 318 by a licensed design professional.

Fig. 4.1—Wood forming system.

Fig. 4.2—Framework forming system.

4.1—Forming systems

There are two broad categories of forming systems: reusable and stay-in-place. Reusable systems are predominantly made from aluminum, wood, or a combination of wood and steel. The initial cost of these durable systems is offset by their repetitive use, which makes them economical. Stay-in-place systems are generally made from polystyrene foam forms connected by plastic ties. The foam form becomes an integral part of the wall, providing insulation and attachment surfaces for exterior and interior finishes. ACI 347 and SP-4 (Hurd 2005) can provide guidance for the selection of forming systems and the specific requirements for each type.

4.1.1 *Reuseable forms*—Reuseable forms create solid concrete walls with a consistent, monolithic thickness from the top of the footing to the top of the wall. The form surfaces are designed with either pattern features, such as bricks or ribs, or are smooth to impart the intended appearance to the wall when they are removed. Insulation may be cast in the wall using one of several proprietary systems.

4.1.1.1 *Wood forms*—Wood forming systems (Fig. 4.1) are used by many contractors and consist of two basic types: job-built and manufactured plywood.

Job-built forms consist of common dimensional lumber and plywood built on site to the requirements of the wall to be constructed. Plywood creates the formed face, and 2× members span across the sheets to brace them against the placement pressures of the concrete.

Manufactured plywood forming systems are designed especially for residential construction. Inside and outside wall forms are set at the same time, and as each form is set into place, ties are positioned and locked into place with attached hardware. The attached hardware secures and aligns the forms as work progresses. All wood components are protected from moisture to facilitate reuse. Steel bars with attached hardware are mounted to the plywood and provide the connecting points for ties and hardware. Simply designed, these systems provide fast, economical, and accurate setups and offer a wide variety of forming combinations that allow the average residential foundation to be formed and placed the same day.

4.1.1.2 *Combination forms*—Combination forms are constructed of a rigid metal framework (typically steel) with plywood sheathing faces (Fig. 4.2) combining the strength of metal with the economy of wood. The wood face can be replaced as it wears from use. These durable components see use in commercial and residential construction, with a wide range of components and sizes available.

4.1.1.3 *Aluminum forms*—Aluminum forms, such as those shown in Fig. 4.3, are higher in initial cost, but their strength, ease of use, and durability have proven to be cost effective for medium- to high-volume contractors. Aluminum forms with a brick patterned face (Fig. 4.4) are used in some regions of the country because the finished wall can be painted to resemble a brick foundation.

Aluminum that has not been treated or properly cured for use in forming concrete will produce a reaction with the alkali, resulting in a damaged finished surface. These forms can be chemically treated or cured through a minimum of two contacts with concrete placements to prevent the affected surface conditions.

4.1.2 *Stay-in-place forming systems*—The majority of the stay-in-place form systems are ICFs. Benefits of ICF construction include low materials cost, easy handling due to their very light weight, integral attachment surfaces for exterior and interior finishes, and insulation values exceeding that of typical wood-framed walls. It is important that the ICF installer follows the manufacturer's instructions for design and installation.

ICF systems vary from one system to another based on the primary configuration of the forming module. There are three main variations within the ICF industry. These differences refer to the shape of the concrete within the form.

4.1.2.1 *Flat or solid systems*—Similar to walls formed with reusable forms, flat or solid systems create a concrete with a constant thickness between two layers of foam insulation forms (Fig. 4.5). The forming units consist primarily of planks or strips configured similarly to traditional reuseable form systems. Two flat sheets of foam insulation are installed and connected by ties to create the concrete cavity. The insulation board is typically about 2 in. (50 mm) thick and can be set vertically or horizontally, depending on the configuration of the system. Both expanded and extruded polystyrene sheets are used in planks. Cavity width is controlled by the tie length.

4.1.2.2 *Block systems*—Block systems are molded foam blocks of expanded polystyrene that resemble large interlocking children's blocks (such as Legos®). They are stacked in a running bond and include an edge detail that interlocks each block to the adjacent unit. Block systems may incorporate the ties, or the ties may be inserted on site, or, in some screen grid systems, the foam plastic serves as the tie. Block systems primarily represent the two structural designs known as waffle grid and screen grid (post and beam), although they too can produce a flat or solid wall.

The system style known as waffle grid is named by the configuration created by a series of concrete-filled horizontal and vertical cylinders with a web of concrete between the cylinders that resembles a waffle (Fig. 4.6).

Similar to the waffle grid, the screen grid (post and beam) style creates a concrete grid of horizontal and vertical cylinders. Molded insulating foam, however, extends through the form to each face. If all of the foam was removed, this would appear similar to a very thick window screen (Fig. 4.7).

4.1.3 *Ties*—One common component for all flat forming systems is the form tie. Ties are regularly spaced connectors that hold the form system in place and resist the internal pressure of the fluid concrete during placement. They provide attachment points to support reinforcing bars. Ties may provide an attachment surface for interior and exterior finishes. Ties are made from steel, plastic, or composite material, and can be round or rectangular in cross section. It is important to follow the form system manufacturer's instructions regarding tie selection and installation. Figure 4.8 through 4.11 show a variety of common ties found in forming systems today.

Fig. 4.3—Smooth aluminum forms.

Fig. 4.4—Aluminum brick forms.

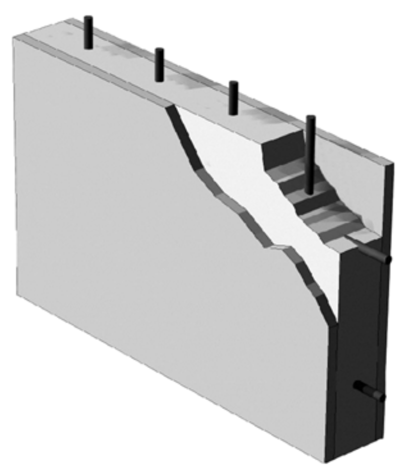

Fig. 4.5—Flat ICF system.

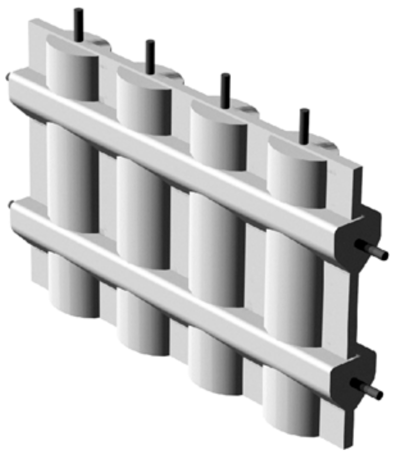

Fig. 4.6—Waffle grid system.

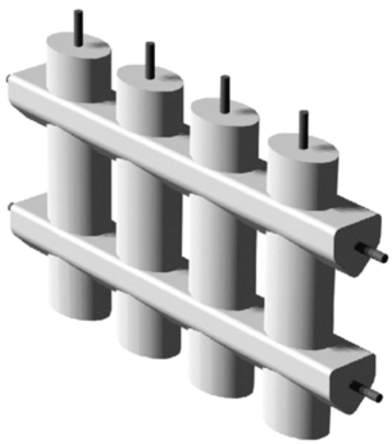

Fig. 4.7—Screen grid system.

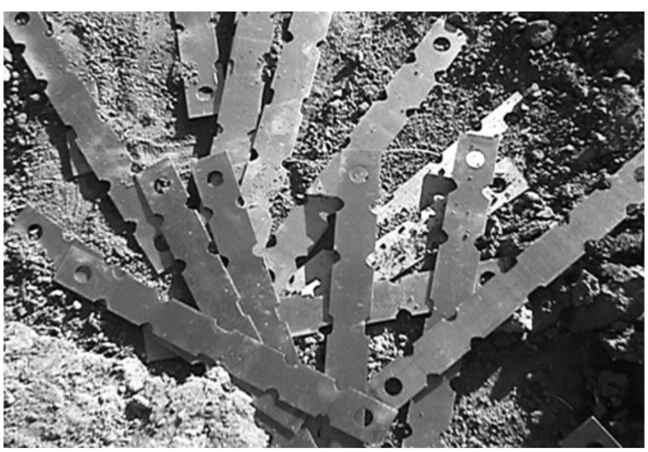

Fig. 4.8—Typical flat tie for aluminum forming system.

4.2—Precast systems

Precast systems also fall into two categories: insulated shell panel and insulated traditional panel. In both systems, the wall is combined with insulation to provide energy efficiency below or above ground.

4.2.1 *Precast insulated shell panels*—Precast shell systems, typically shaped like a "[", are premanufactured panelized wall systems used either below ground or above ground (Fig. 4.12). The panels consist of an exterior face of concrete between 1.5 and 2 in. (38 and 50 mm) thick. Monolithically cast with this shell face are top and bottom beams of reinforced concrete that are approximately 10 in. (250 mm) wide. Concrete studs spaced at regular intervals are attached to the face shell through rigid insulation boards and are faced with wood nailers for attaching interior finishes. This construction system is traditionally placed on crushed stone fill rather than concrete footings.

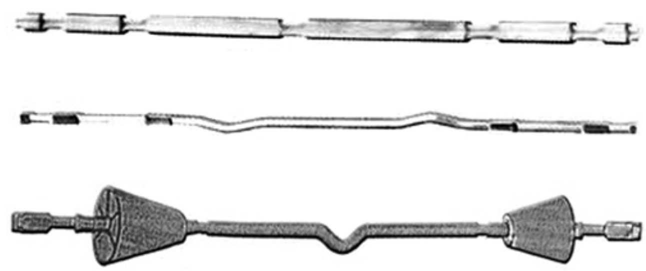

Fig. 4.9—Common form ties used with wood forming systems.

Fig. 4.10—Typical fiber-composite form tie for hybrid systems.

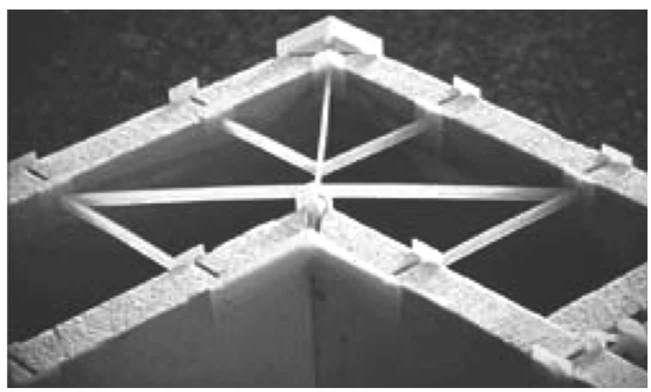

Fig. 4.11—Example of plastic corner tie for panel ICF systems.

4.2.2 *Traditional precast insulated panels*—Traditional precast panel systems consist of two monolithic layers of concrete with a layer of continuous insulation separating them. The concrete layers, one a thicker structural layer located on the inside of the wall and the other a thinner layer providing protection and architectural finish possibilities, are physically connected through the insulation. Figure 4.13

Fig. 4.12—Precast insulated shell panel system.

Fig. 4.13—Precast insulated traditional panel system.

shows a typical panel being set in place with an added thin brick exterior feature integrated into the precast panel.

4.3—Reinforcement

Steel reinforcement in walls consists of reinforcing bars placed horizontally, vertically, diagonally, or a combination of these to the direction of the wall for structural reinforcement, temperature and shrinkage reinforcement, or to control re-entrant crack development.

4.3.1 *Structural reinforcement*—Structural reinforcement is reinforcement required to resist applied loads, rather than reinforcement required only to resist shrinkage and temperature effects. Depending on the magnitude of the vertical and lateral loads applied to the wall, the wall may be designed without reinforcement as a plain structural concrete wall in accordance with Section 7.2.1 of ACI 332; as a moderately reinforced wall with less reinforcement than the minimum required for a reinforced concrete wall; or as a reinforced concrete wall fully satisfying all applicable requirements for reinforced concrete in accordance with Section 7.2.2 of ACI 332. When structural reinforcement is required, it should be in accordance with the empirical tables of ACI 332, the IRC, or determined by a licensed design professional and shown on contract documents.

Standard construction practice for the installation of steel reinforcement is shown in Fig. 4.14.

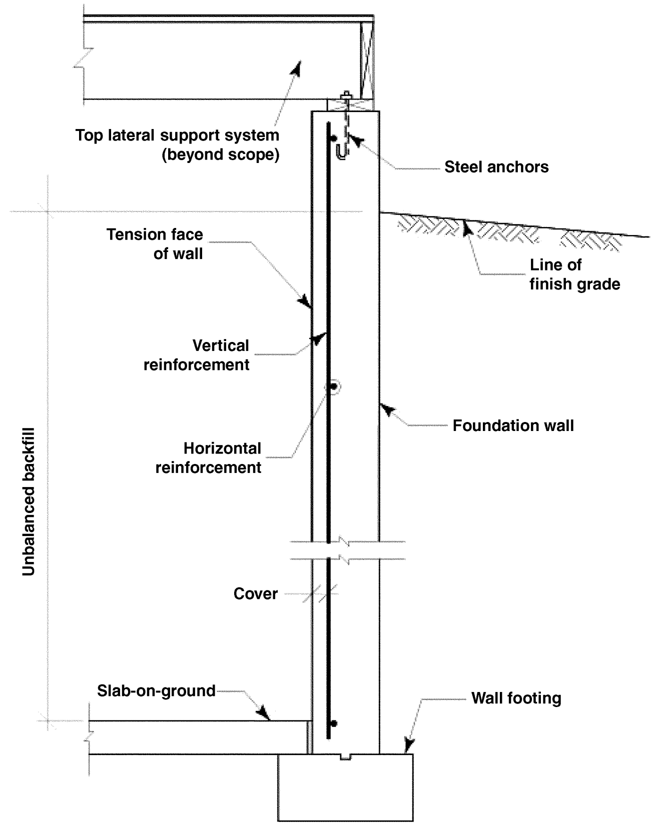

Fig. 4.14—Installation of structural reinforcement.

4.3.2 *Temperature and shrinkage reinforcement*—Providing temperature or shrinkage reinforcement can be effective in minimizing crack width. Walls that are considered to be plain structural or unreinforced should still include horizontal steel reinforcement to minimize the effects of shrinkage on crack formation. Figure 4.15 also shows the typical location for this horizontal steel. ACI 332 provides the minimum requirements for the quantity of reinforcement.

Re-entrant corners are created at openings and at changes in geometry. These are common locations for cracks to initiate from shrinkage stresses. To minimize the resulting crack width at these locations, reinforcement should be placed as indicated in Fig. 4.16 and 4.17.

4.3.3 *Miscellaneous reinforcement*—Wall reinforcement or dowels are used to positively connect other concrete elements, such as stoops, to a wall. Reinforcement used for these purposes should be installed as indicated in Fig. 4.18.

4.3.4 *Reinforcement details*

4.3.4.1 *Cover*—Reinforcing bars in walls in contact with earth should have a minimum of 2 in. (50 mm) of cover. The cover can be reduced to 0.75 in. (19 mm) on the interior of the walls.

4.3.4.2 *Laps*—Laps for horizontal reinforcement should be a minimum of 24 in. (610 mm) or 30 bar diameters, whichever is greater (Fig. 3.22). Vertical reinforcement is generally full height. If a lap is required, it should not be less than 24 in. (610 mm) unless a licensed design professional is consulted.

4.3.4.3 *Embedment and connections*—Garage walls and foundation walls, stoops and foundation walls, and other

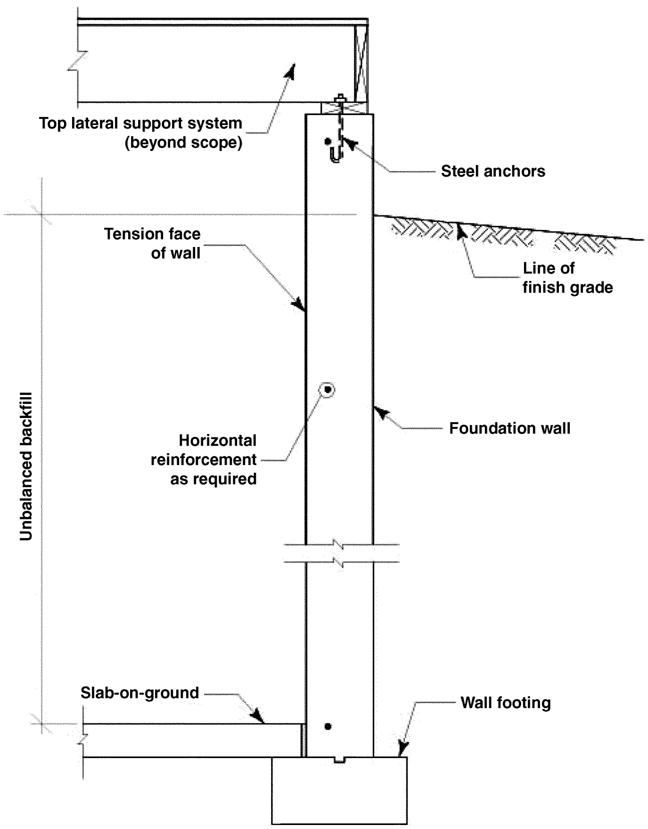

Fig. 4.15—Installation of horizontal reinforcement.

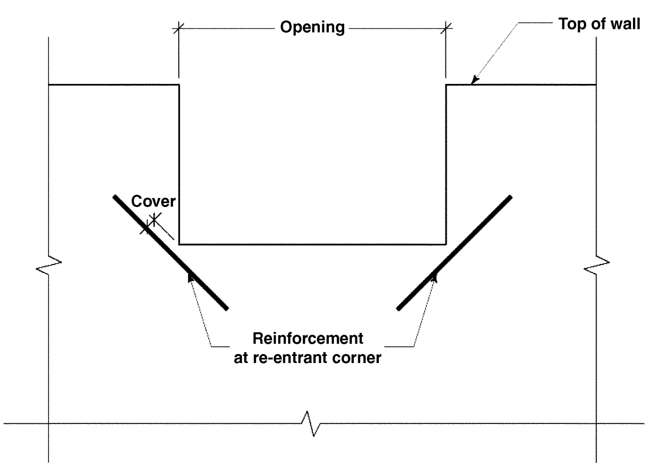

Fig. 4.16—Cracking control below openings.

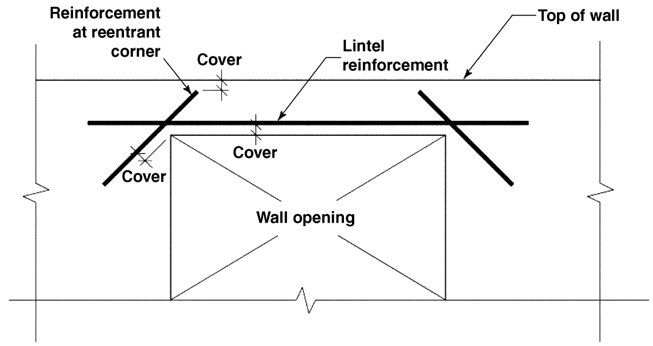

Fig. 4.17—Cracking control above openings.

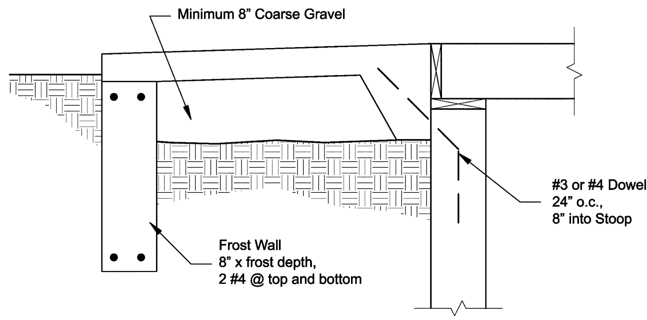

Fig. 4.18—Typical stoop attachment.

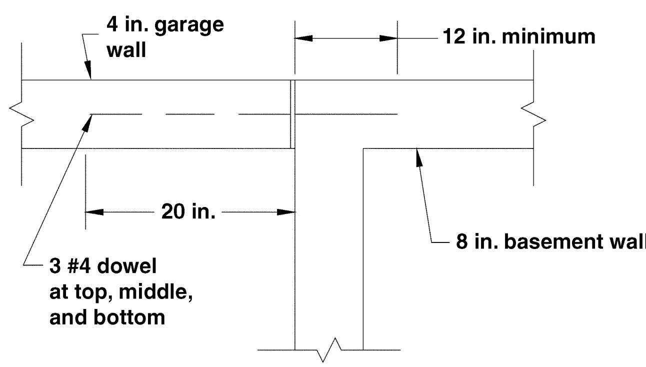

Fig. 4.19—Steel rod connection with embedment.

concrete elements that may be cast in separate placements should be tied together to prevent differential settlement. If the elements are cast at the same time, continuous or bent reinforcing bars are preferred. If the elements are cast separately, postdrilling and embedment of the reinforcing bars is required. Figure 4.19 and 4.20 show two designs that should be considered for connecting concrete elements.

At no time should aluminum elements become embedded in the concrete unless they are coated to protect against the alkalis. The cement paste will react with the raw aluminum, resulting in degradation to the element and damage to the concrete.

4.3.5 *Construction joints*—When two concrete wall elements are cast separately, the continuity of the structural wall can be maintained by using a keyed joint or reinforcing bars to minimize differential movement. The joint created is commonly referred to as a construction joint. These joints typically occur at unfinished placements where the concrete work is concluded for the day. Concrete connections should be installed according to Fig. 4.21 or 4.22.

4.4—Geometry

4.4.1 *Wall heights*—Eight feet (2.5 m) has traditionally been the most common wall height that coincides with the manufacturing module of most building products. Nine and 10 ft (2.7 and 3.0 m) walls are becoming increasingly popular in new residential construction. Ten foot (3.0 m) or higher walls are sometimes used in special site conditions and in above-ground residential construction. Wall configurations not addressed in prescriptive tables of ACI 332 or the IRC should be designed by a licensed design professional.

4.4.2 *Wall thickness*—Concrete foundation walls with removable forms are usually 8 or 10 in. (200 or 250 mm) thick with little or no reinforcement. The IRC allows foundation walls with a minimum concrete thickness of 5.5 in. (140 mm) (2003 IRC, Section R611). Wall designs may vary based on loading or design conditions not described in ACI 332. These conditions can be referenced in the IRC or designed by a licensed design professional.

4.4.3 *Dimensional tolerances*

4.4.3.1 *General*—All construction, including concrete walls, is afforded some deviation from design dimensions. Concrete foundation walls should be considered within tolerance if these conditions are met:

- The deviations do not cause the structure to be structurally unstable;
- The deviations do not encroach on areas reserved for other work;
- The deviations do not impede other trades from doing their work; and
- The deviations do not place the structure out of compliance with governing codes.

4.4.3.2 *Common deviations*—Residential foundation walls should follow the generally accepted tolerances listed as follows when the maximum length of any wall section does not exceed 60 ft (18 m); the maximum length of any diagonal across an area does not exceed 75 ft (23 m); or when the maximum overall dimension for any part of the foundation does not exceed 75 ft (23 m). When a residential construction exceeds these dimensions, the tolerances for cast-in-place concrete as found in ACI 117 may be applied. The following tolerances are recommended:

Location of:
Foundation wall supporting masonry (deviation of edge of wall from design location)..........................±0.5 in. (13 mm)
Foundation wall supporting nonmasonry framing (deviation of edge of wall from design location)............±2 in. (50 mm)
Embedment element (deviation from design location)
....±1 in. (25 mm)
Blockout (deviation of edge of opening from design location)
....±1 in. (25 mm)
Plumbness (difference between the top and bottom of a wall as measured from a vertical plane)
....±1 in. in 8 ft (10 mm in 1m)
Levelness (deviation of top of wall).........±0.75 in. (19 mm)
Thickness (deviation from designed thickness)
....±0.5 in. (13 mm)
For walls over 36 in. (910 mm) thick
..................................+1 in. (25 mm), –0.75 in. (19 mm)
Opening width (deviation of size of opening)
....+1 in. (25 mm), –0 in. (13 mm)
Height (difference between height of wall and design height)
....±0.5 in. (13 mm)
Bowing, horizontal (between two corners or offsets)
.... 1 in. (25 mm)

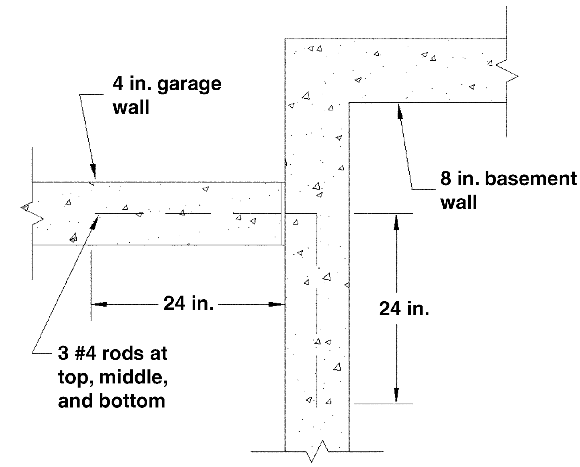

Fig. 4.20—Bent rod connection.

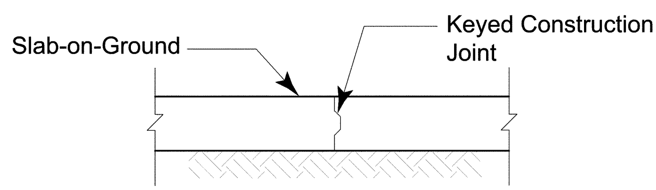

Fig. 4.21—Keyed construction joint.

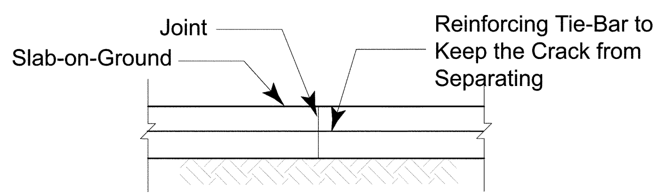

Fig. 4.22—Tie-rod construction joint.

Length of wall:
Overall dimension of foundation (deviation of horizontal dimension of wall from design measurement)
supporting masonry .... ±1 in. (25 mm)
not supporting masonry .... ±2 in. (50 mm)
Wall segment (deviation of dimension of wall segment from design measurement) .... ±0.5 in. (13 mm)
Squareness of: (deviation in dimension of a foundation diagonal)
Foundation supporting masonry .... ±1.5 in. (38 mm)
Foundation not supporting masonry............. ±2.5 in. (64 mm)

4.4.4 *Surface imperfections*—The quality of the finished concrete wall may directly impact the level of comfort the homeowner has with the finished product. The contractor should plan the placement of concrete to minimize surface imperfections, such as placement lines and air pockets (bug holes), and shrinkage reinforcement to minimize the expansion of microcracks to larger, more visible defects. The following describe the common feature limitations, taking into consideration both performance and appearance.

Crack width (maximum width of crack).......<0.125 in. (3 mm)
Surface air pockets (maximum size of surface air pocket)
.... <0.75 in. (19 mm)

Fig. 4.23—Wall forms stepping from basement foundation wall to garage foundation wall.

Fig. 4.24—Brick ledge in form.

Fig. 4.25—Brick ledge.

Fig. 4.26—Beam pocket.

Imperfections that exceed these limitations should be repaired. Cracks 1/8 in. (3 mm) or greater should be injected with an epoxy bonding agent to fill the void created and secure the fissure. Bug holes and other surface blemishes should be repaired as described in Section 4.5.9. Patching of the exterior should be done to ensure that any potential freezing-and-thawing cycling of the final finish will not re-expose the imperfections.

4.4.5 *Wall steps*—Wall steps, such as the type shown in Fig. 4.23, typically occur in conjunction with footing steps at transitions from garages to basement walls (also known as a discontinuous footing), in walk-out basements, and in other locations where grade changes exist. The height and length of the steps typically coincide with the forming module.

4.4.6 *Brick ledges*—The upper section of a foundation wall is often reduced in thickness to allow for the construction of a brick veneer (Fig. 4.24 and 4.25). ACI 332 provides the requirements for these regions limited to 4 in. (100 mm) minimum thickness and requiring special reinforcement. If the height of the reduced wall thickness is greater than 24 in. (610 mm) and the height of unbalanced backfill is greater than 4 ft (1.2 m), it should be reviewed by a licensed design professional, or the thickness of the wall should be increased.

4.4.7 *Beam and joist pockets*—The foundation wall can be reduced in thickness locally to allow for beams and floor joists to be set below the top of the foundation (Fig. 4.26). This condition assumes that the floor structure system is attached at the point where the wall thickness is reduced. If different conditions are used, the detail should be reviewed by a licensed design professional.

4.5—Wall construction

Manufacturer's systems usually require many individual components that are designed to work together to create a functional assembly. Only accessories (including ties, pins, and wedges) provided by the manufacturer or specifically engineered for the system should be used. ACI 347 and SP-4 (Hurd 2005) can provide guidance for the methods used to form concrete walls and brace them before, during, and after concrete placement until sufficient strength has been attained.

4.5.1 *Setting forms*—Basic construction skills are necessary to set the forms. Reuseable forms should be cleaned and treated with form oil or a release agent before each setting. The forms should be braced to remain stable during the placing of the concrete to maintain the tolerances outlined in

Section 4.4.3. The overall layout, openings, and tolerances should be checked before concrete placement. A final check and minor adjustments should be made immediately after placement of the concrete but before the initial set has occurred to ensure that the walls are straight and level within tolerances. ICF forming systems should be assembled and set per the manufacturer's installation guide.

4.5.2 *Wall openings*—Blockouts, including window and door bucks, beam pockets, and utility penetration sleeves, are installed in the forms before concrete placement. It is critical to check locations of blockouts during installation and again before concrete placement. This is also an excellent time to confirm installation of reinforcing steel around openings and in lintels.

4.5.2.1 *Doors and windows*—Door and window bucks are typically fabricated from dimensional lumber, metal, or extruded vinyl shapes. Internal bracing is frequently required to prevent bowing, racking, or collapse of these bucks during concrete placement.

4.5.2.2 *Wall penetrations*—Smaller openings, pockets, and through-wall penetrations can be created with blockouts from scrap lumber, foam insulation, or PVC pipe. The blockouts should be fastened securely to the formwork to prevent them from shifting or falling into the formwork under the heavy load of falling concrete. Refer to details in Section 4.4 for reinforcement placement details around such openings.

4.5.3 *Form release agents*—All reusable forming systems use a coating applied to the forms before each use to aid in the removal of forms. A variety of chemicals are used for this purpose, including oil, water, and detergent-based formulations (Fig. 4.27). Manufacturers' recommendations should be followed in the use of form release agents. Some release agents may produce discolorations or react adversely with the forms or finish materials, such as waterproofing, insulation, or paint. If doubt exists, it may be prudent to test the effect of a new form release agent in noncritical or nonvisible areas before widespread use.

4.5.4 *Bracing and scaffolding*—Proper installation of formwork is critical to the success of any construction project. Forming systems should be stable enough to withstand the pressure of concrete placement and the loads from workers. A variety of bracing systems can be employed, some of which include turnbuckles and integral scaffolding. Recommendations for determining concrete pressures and bracing forces are provided in ACI 347 and SP-4 (Hurd 2005).

ICFs will often require more bracing than removable forms. ICF systems employ wood or metal bracing. Wood systems may consist of corner bracing and intermediate braces. Many manufacturers provide recommendations for bracing their systems.

4.5.5 *Concrete delivery and placement*—Methods for placement of concrete vary depending on site conditions, availability of specialized placement equipment, and cost. Care should be taken to avoid segregation during placement. Methods for placing concrete include pumps, conveyors, cranes and buckets, and directly from the truck mixer chute. With all methods, concrete should be placed as close as possible to its final location to reduce the possibility for segregation.

Fig. 4.27—Spraying release agent on gang form (photo courtesy of B.E.P. Forming).

4.5.5.1 *Preplacement preparation*—Site conditions influence the concrete placement. Before ordering the concrete, the most appropriate method and location from which to place the concrete should be determined. Before any large equipment arrives on site, the site conditions should be reviewed and discussed with the operator. Inspection of any overhead lines should be completed. Before the placement of concrete, construction debris, snow, water, ice, or mud should be removed from the cavity.

4.5.5.2 *Placement*—When possible, placement of concrete should begin at the corners and work around the building. The forming system manufacturers' specific recommendations should be followed for maximum lift height. Successive lifts should be blended with previous lifts by rodding or vibration.

Concrete should be placed within 1-1/2 hours of batching and before the concrete truck drum has undergone 300 drum revolutions, unless the mixture has been designed accordingly. In warm weather or when other conditions exist that may promote a rapid early set, the time period from mixing until placement may need to be reduced or a retarding admixture may be needed. If, however, the temperature of the concrete is within the range of 55 to 100 °F (13 to 38 °C) and the amount of water added to the mixture to achieve workability does not exceed the mixture proportion, the 90-minute discharge time may be exceeded while maintaining the specified concrete properties during the placing operations. Refer to ASTM C 94 for additional guidance concerning ready mixed concrete.

4.5.5.3 *Direct chute*—Placing concrete with a direct chute (Fig. 4.28) involves positioning the truck so that the concrete can be delivered directly into the forms. This method works well when access to the site and the foundation at multiple sides is good, and where the final location of the concrete is lower than the chute.

4.5.5.4 *Crane and bucket*—Site logistics may require the use of a crane and bucket to place the concrete. Cranes require a level area, large enough to set their outriggers, close to the work area, and accessible for concrete trucks.

Fig. 4.28—Direct chute placement from truck.

Fig. 4.29—Placement by pumping.

4.5.5.5 *Pumping*—Pumping is a popular method for placing concrete, and is the most common and economical system when placing concrete in ICF forms. Pumps can be used with virtually any site conditions, provide a continuous and rapid flow of concrete, and have the advantage of placing the concrete close to its final location. Figure 4.29 shows a pump placing concrete along the top of a foundation wall as directed by the crew. When placing concrete in thin wall sections 8 in. (200 mm) or less or in ICF forms, the operator should be instructed to add a reducer fitting to the end of the hose to slow the speed of the falling concrete for a more controlled placement process.

4.5.5.6 *Conveyors*—The use of conveyors has increased in recent years. Conveyors have similar advantages to boom pumps. They can also be used for the placement of other materials on the job site (Fig. 4.30).

4.5.6 *Consolidation*—Vibration is the most common method for consolidating fresh concrete. Consolidation is necessary to develop the design properties of the concrete.

Fig. 4.30—Conveyor placement with telebelt.

Fig. 4.31—Vibration by rodding with two-by-four (photo courtesy of B.E.P. Forming).

The purpose of consolidation is to densify the concrete in the forms. This releases trapped air and fills any pockets or voids with concrete. Inadequate consolidation may cause imperfections, especially around corners and openings. Methods commonly employed for walls formed with reusable forms include rodding with a piece of dimensional lumber like a common two-by-four (Fig. 4.31) or a steel reinforcing rod; the use of an internal vibrator (Fig. 4.32); or low-frequency external vibration. Walls formed with ICF systems should only use internal vibration to densify the concrete. More information can be found in Gajda and Dowell (2003) regarding vibrating ICF walls.

During rodding and vibrating of the concrete, it is important to penetrate the previous placement by at least 6 in. (150 mm). It is possible to overvibrate concrete, especially concrete that is overly wet, causing the large aggregate to sink to the bottom of a lift. Proper procedures for consolidating concrete can be found in ACI 309R or by contacting the form manufacturer.

The advent of SCC, a mixture proportion that uses admixtures to turn very low slump into highly flowable concrete, has greatly improved finishes for vertically formed surfaces. The concrete is designed to flow throughout the formed cavity easily with little vibration other than what is required to move the trapped air pockets from along the sides of the forms. SCC offers beneficial attributes including less

Fig. 4.32—Mechanical vibration with internal vibrator (photo courtesy of B.E.P. Forming).

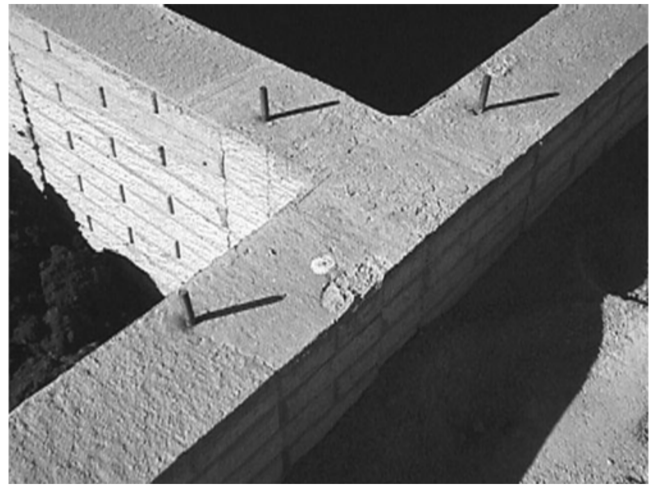

Fig. 4.33—Location of anchor bolts.

Fig. 4.34—Hurricane strap anchorage.

placement labor, improved finish quality, and reductions of possible surface repairs.

4.5.7 *Anchorage*—The top of the foundation wall serves as the primary attachment point for the frame of the above-ground structure, while the frame provides the top lateral support for the foundation wall. The floor structure of the building transfers horizontal loads to the side of the structure or to adjacent walls through diaphragm action. The keyway or dowels in the footing or the basement floor slab usually provide the lateral support at the bottom of the wall. The sill plate attachment should also resist vertical uplift and horizontal loads on the structure during high winds, earthquakes, the backfilling operation, and hydrostatic pressure.

Anchorage of light framing is usually accomplished with steel anchor bolts a minimum of 0.5 in. (13 mm) in diameter with a minimum of 7 in. (180 mm) embedded in the concrete (Fig. 4.33). Maximum spacing between bolts is 6 ft (1.8 m) on center and 12 in. (300 mm) from the end of each section. Every single piece of sill plate should be attached with at least two bolts. Local codes and Seismic Categories D, E, and F may require additional anchorage not covered in this document. High wind regions also require a closer spacing of anchors to the foundation wall when using metal stud framing systems. The governing code should be reviewed for specific requirements. Anchor bolts should project through the plate so that the threads protrude beyond the nut when tightened.

Anchor straps are becoming increasingly popular as a method of sill plate attachment. Figure 4.34 shows an example of one type commonly referred to as hurricane straps. The straps are an engineered system, and therefore, the manufacturers' recommendations with regard to spacing, embedment, and attachment procedures should be followed. It is very important that the correct procedure be used to connect the sill plate to the foundation with anchor straps, or uplift cannot be adequately resisted. In regions with high seismic requirements, seismic straps (Fig. 4.35) are required to connect the sill plate to the foundation wall. These straps or anchors are embedded in or bolted to the foundation wall and bolted to the sill plate to provide capacity to transfer the much higher lateral loads between the two structural components.

Before installing this type of anchor, it should be confirmed with the building official that these will be allowed. It is good practice to install a compressible sill sealer under the sill plate to minimize air infiltration.

4.5.8 *Removal of forms and bracing*—Supporting forms, braces, and shoring should not be removed from wall forms until adequate strength is attained. Depending on climate conditions, curing procedures, and the mixture proportions, the concrete should develop a compressive strength of 500 psi (3.5 MPa), which is typically sufficient for the wall to sustain its own weight in as little as a few hours after initial set. It is recommended, however, that the forms be left in place for a minimum of 12 hours.

It is very important for the contractor and builder to consider bracing the wall after the forms are removed or delay the backfilling until the floor deck, including subfloor sheathing, is completed and 75% of the design strength of the concrete has been reached. Foundation walls are designed to be supported both at the top and base to resist the lateral

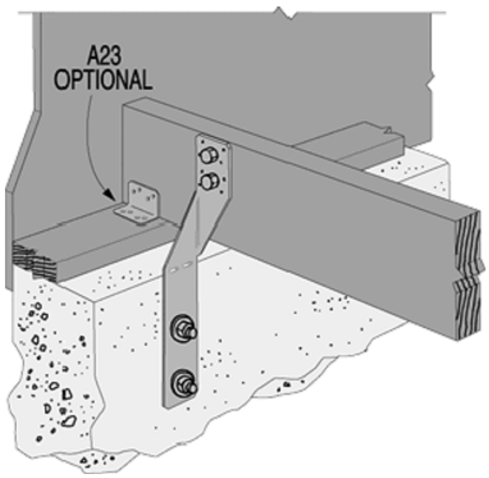

Fig. 4.35—Common seismic strap anchorage (figure courtesy of Simpson Strong-Tie).

Fig. 4.36—Honeycomb at cold joint between placements.

loads of the soil. Walls that are backfilled without bracing or the floor deck in place are vulnerable to cracking, horizontal displacement, or bowing.

4.5.9 *Patching and finishing*—If patching is required in the new concrete, it should begin as soon as possible after the forms are removed. Projections and fins should be removed by chipping. Figure 4.36 shows an example of an area that should be considered for patching. Surface defects, tie holes, and small areas of honeycombing (under 50 in.^{2} [0.3 m^2] and less than 0.5 in. [13 mm] deep) can be repaired by thoroughly wetting the surface and applying a patching mortar of 1 part portland cement to 2-1/2 parts sand. The use of the job cement, however, increases the potential of color matching if this is an important criteria for the project.

Large areas of honeycombing (greater than 50 in.^{2} [0.3 m^2]), defects deeper than 0.5 in. (13 mm), and areas where reinforcing steel are exposed should be chipped away to a depth of not less than 1 in. (25 mm) or to where sound concrete is encountered. The sides of the recess should be approximately perpendicular to the face of the wall to ensure mechanical anchorage. The area should be filled with a patching mortar as described previously.

ACI 546R should be reviewed for additional information regarding recommended procedures for patching various concrete surface irregularities.

4.6—Curing and protection

The process of curing concrete is intended to maintain satisfactory temperature and moisture content in the concrete until the desired properties are attained. Concrete that is improperly cured can result in a reduction in strength and durability as well as an increase in porosity. Concrete continues to gain strength and durability as curing takes place, affecting the timeline as the construction process progresses. Refer to ACI 308R for specific procedures and recommendations for curing.

The concrete should reach sufficient strength or be protected before proceeding with the construction of the floor system or the backfilling operation. Typically, a wood floor system could be constructed on the concrete walls as early as 72 hours after casting, depending on weather. Hot weather conditions (90 °F [32 °C] and above), temperatures below freezing, and extremely windy conditions require special attention (ACI 308R).

4.6.1 *Freezing weather*—When the ambient temperature is low enough for the concrete to reach a frozen state before reaching a strength of 500 psi (3.5 MPa), protective measures should be considered. Protective measures include the addition of blankets or protective sheets, auxiliary heat, tents, admixtures, increased cement content, use of high-early-strength cement (Types III or HE), and higher concrete delivery temperatures. These measures should remain in place or be effective until the concrete strength reaches a minimum of 500 psi (3.5 MPa). Studies, such as the "Cold Weather Research Report" by the Concrete Foundations Association (2004), have indicated that if the concrete freezes after 500 psi (3.5 MPa) is attained, it will continue to gain strength when the temperature rises above freezing, assuming there is sufficient water in the concrete for hydration to continue. One way of determining the in-place strength of concrete is known as maturity, which is the prediction of strength gain based on the known material properties of the concrete, the compressive strength performance of those properties, and the temperature curve generated during the curing condition.

Leaving the forms in place, draping the wall with plastic or blankets, or both, during the period of freezing temperatures will help retain the heat of hydration. If the forms are removed too early and the wall freezes, protection should be applied as soon as possible. The temperature should be increased and existing moisture retained until the required strength is attained. ACI 306R provides reference to methods of determining maturity, protecting concrete, and strengths that should be attained for freezing conditions. The use of high-early-strength Type III or Type HE cement and admixtures can shorten the time period for initial set if freezing weather is imminent. The insulation present in ICF systems provides sufficient protection in most cases.

4.6.2 *Hot weather*—The greatest problem in hot weather is rapid hydration of the concrete and the resulting loss of workability. This problem can be reduced by using retarders or by lowering the concrete temperature by using evaporative cooling of coarse aggregates, chilled water, or ice. It is important in hot weather that the concrete be placed as soon as possible in the forms and that successive lifts be placed as quickly as possible to avoid cold joints created from initial setting of the prior lift. Additional rodding or vibration may be required to ensure that successive lifts are blended. If a high *w/cm* is used, the concrete can crack due to shrinkage caused by the rapid evaporation of water before the initial set has been reached. Refer to ACI 305R for specific procedures and recommendations on hot weather concreting.

4.6.3 *Windy conditions*—Windy conditions and low humidity can cause cracking once the forms are removed. This is especially critical during the first 3 days following placement. The wind and lower humidity can cause rapid drying of the concrete before sufficient hydration has taken place to achieve the desired strength. This can lead to shrinkage cracks and substantial reduction in the final strength of the concrete. If wind speeds are anticipated above 30 mph or relative humidity is expected to drop below 40% following form removal during the initial 7 days after placing, the exposed walls should be coated with curing compound or draped with plastic or similar materials to minimize the effect of wind and low humidity. The selection of the curing compound, if used, should be checked for compatibility with any bonding or penetrating material that is intended for the finished wall.

4.7—Moisture protection

Moisture protection falls under two descriptions: waterproofing and damp-proofing. Many individuals incorrectly use the terms interchangeably. Each system has a different purpose, with different levels of moisture protection.

4.7.1 *Damp-proofing*—Concrete can absorb a relatively small amount of liquid water by capillary action (known as capillarity or sorptivity) (Martys and Ferraris 1997). Damp-proofing is intended for use in areas that have minimal or intermittent exposure to exterior moisture. All foundation walls below ground that enclose basements or crawl spaces should be damp-proofed as a minimum degree of protection. Damp-proofing (Fig. 4.37) is typically an asphalt-based coating that is sprayed or brushed on the exterior wall surface to minimize moisture transfer through the wall. Several other systems, including plastic sheathing, are also available for this purpose. The damp-proofing should extend from the top of the footing to finished grade. Damp-proofing systems reduce water vapor penetration at the exterior surface, but lack the ability to span small cracks that may form in the wall. This limitation makes them unsuitable as a waterproofing system. All materials should be installed in accordance with manufacturer's recommendations. For ICFs, the damp-proofing and waterproofing should be compatible with the ICF material. Most ICF companies supply or recommend approved damp-proofing or waterproofing materials for their systems. It is important to understand that the level of protection by damp-proofing is only as thorough as the degree of application. Pinholes and thin applications will reduce their effectiveness. If the interior of the concrete wall is to be covered (with an insulation furring system and drywall) or an applied coating, those materials should be capable of withstanding the level of moisture afforded by the damp-proofing. As the term indicates, damp-proofing is not a waterproof system. If a completely dry interior space is desired, a waterproofing system should be considered.

Fig. 4.37—Damp-proofed wall.

4.7.2 *Waterproofing*—In areas where a high or fluctuating water table exists, where there are intermittent hydrostatic conditions, or where required by code, foundation walls enclosing habitable, garage, or storage spaces below ground should be waterproofed and properly drained. Waterproofing materials and systems are specifically designed to prevent the natural process of water absorption by concrete as well as transmission of moisture through cracks and imperfections. Waterproofing materials come in many of different forms. They include specialized plastic membranes (Fig. 4.38), sprayed and troweled coatings, and products composed of a combination of materials. Waterproofing materials should be elastic and able to span a crack of 0.125 in. (3 mm) under a head of 16 ft (4.8 m) of hydrostatic head pressure without failure. The membrane should also be resistant to, or protected from, penetration during the backfilling operation.

4.7.3 *Drainage*—Drainage is a key element in wall performance, and should be used in conjunction with waterproofing and damp-proofing systems. If the backfill material (such as clay) retains water, it can create lateral pressures far greater than those for which the wall was designed, resulting in a structural failure, cracks, or leaks. There are two critical components in a proper foundation drainage system: the backfill material and the drain piping system for removing the water (Fig. 4.39).

4.7.4 *Backfill for drainage*—Materials conforming to Group I of the unified soil classification as provided by ASTM D 2487 may be used around and up to 1 ft (300 mm) above the drain pipe. Installing coarse granular fill or drainage boards against the foundation wall above the

Fig. 4.38—*Waterproofing sheet application.*

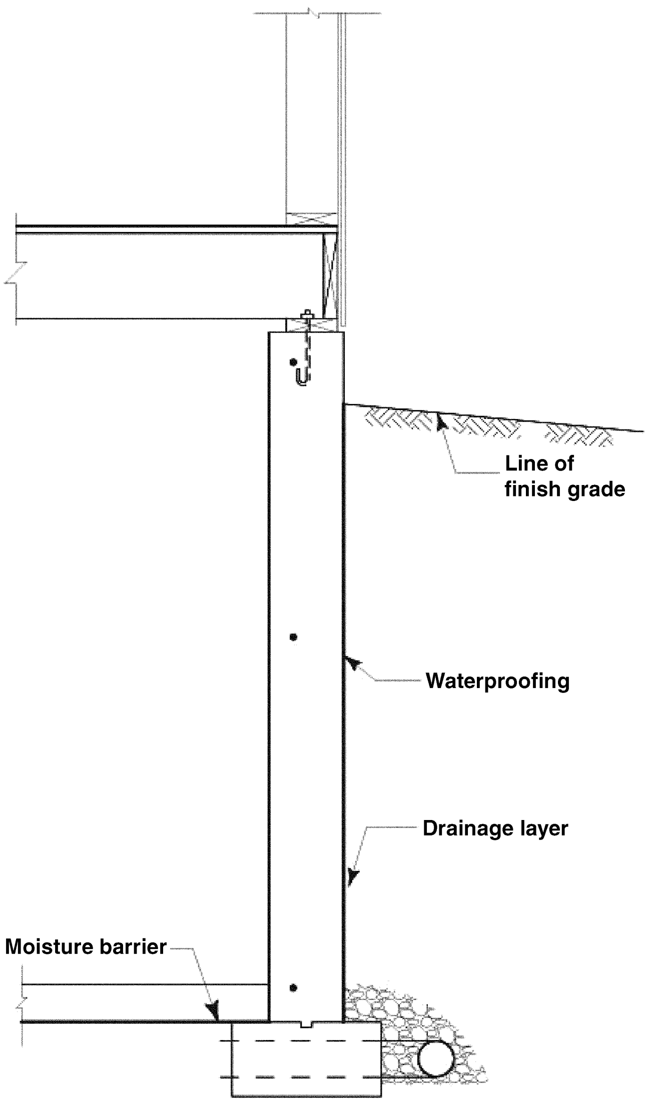

Fig. 4.39—*Well-drained foundation wall.*

footing will to allow water to filter to the drainage system and not collect against the wall.

4.7.5 *Drainage systems*—The drainage system collects and removes the water from around the footing, either by

Fig. 4.40—*Tile system installed and covered with granular fill.*

draining via gravity to daylight, or by a sump pump system. The system should be installed level around the building to prevent collection of water and sediment in low areas. Placement should be either on top of the footing or with the top of the pipe no lower than the top of the footing. The pipe should be covered with granular material (and a filter fabric if the material contains fines) (Fig. 4.40). Several new systems are now available that act as both the footing formwork and foundation drainage tile.

4.8—Backfilling

4.8.1 *Wall support*—Residential foundation walls are assumed to be fully supported at the top and bottom when applied moments and shears (demand loads) are determined. To be fully supported at the bottom, the floor slab should be in place (assuming the slab rests on the footing and is against the wall), or a suitable keyway or steel dowels should be used. Top support assumes that the floor structure and subfloor sheathing are in place. Figure 4.14 shows top and bottom restraint by these two conditions. If backfilling will occur before either of these conditions, additional steps should be taken to prevent a wall failure from the force of the backfill and equipment placing the fill. In such cases, a bracing system should be designed for the construction conditions by a licensed design professional. Backfilling to an unbalanced backfill height of 4 ft (1.2 m) to the intended grade at the corners or where the wall is braced by a change of direction should not present a problem to the integrity of the foundation wall.

The most common method of bracing is the use of dimensional lumber (that is, four-by-fours) braced to the wall and the ground. The top of the brace should be anchored in the top 1/4 of the wall, and should project at approximately a 45-degree angle from the wall (Fig. 4.41). The top and bottom connection and anchorage should be firm to prevent slip when load is applied. The braces should be spaced as determined by the licensed design professional.

4.8.2 *Materials*—Backfilling materials should be pervious materials of Type SM, ML, or better, as classified by ASTM D 2487. They should be of uniform density and free of organic material, debris, frozen material, expansive soils, boulders, and other foreign objects greater than 8 in. (200 mm) in diameter. Porous granular materials are most suitable for backfilling to within 24 in. (610 mm) of the finished grade. The top 24 in. (610 mm) should be backfilled with a less porous or relatively impervious material to aid in the diversion of water from the foundation. Soils and materials that retain water can produce excessive lateral forces on the wall. Organic materials, such as lumber, stumps, and vegetation, should not be allowed in the backfill. They provide conducive conditions for termite infestations and will eventually decompose, increasing the likelihood for settlement. Rock (larger than 8 in. [200 mm] diameter), concrete block, and other large or sharp objects should not be used, as they could damage the wall and moisture-protection systems. They can also leave voids beneath the object. Provisions should be made for some settlement based on the type of material used for backfilling and the amount of compaction used.

4.8.3 *Placement of backfill*—Backfill should be placed in lifts of from 8 to 12 in. (200 to 300 mm) in loose thickness. Some form of compaction should be used between lifts, resulting in a compacted lift thickness of approximately 5 to 12 in. (125 to 300 mm) depending on the soil used, its moisture content (and the equipment used to compact it). The use of a pad vibrator is the most suitable form of compaction for granular materials, while kneading is required for cohesive soils. Other methods can be used, depending on the type of backfill used. Earthmoving and other heavy construction equipment (such as a truck loaded with drywall) should never be used for compaction of the backfill, and should not be driven within 8 ft (2.5 m) of the walls. The finished grade should slope away from the structure at a minimum of a 1:6 ratio for a minimum of 10 ft (3 m).

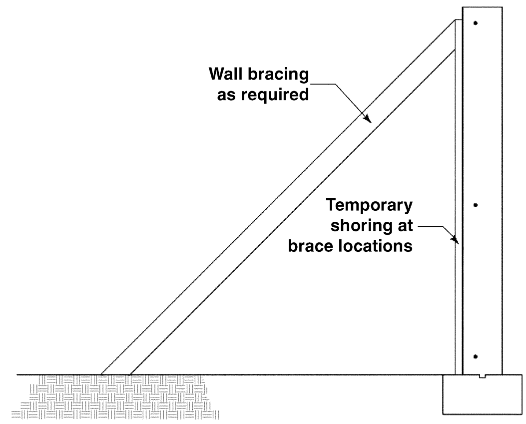

Fig. 4.41—Bracing connection.

Fig. 4.42—Cutback of excavation.

4.9—Safety

Safe practices on a construction site are required for foundation construction. Potential injuries include back injury caused by lifting the panels, broken limbs caused by dropping and handling panels, cuts and punctures from reinforcing, and eye injuries. Materials, chemicals, and methods can all contribute to an unsafe job site. The best method to reduce accidents is to have an approved safety plan. The plan should include information on hazardous materials, correct procedures for all work, and a plan of action if an accident should occur. Several areas of safety are of particular concern to the Occupational Safety and Health Administration (OSHA).

4.9.1 *Cutback and trenches*—OSHA has established requirements for excavations and trenches (Fig. 4.42) that apply to foundation contractors. The space between a foundation wall form and an excavation bank is equivalent to a trench in regard to the need to provide a protective system and means of egress. The space between the excavation and an erected form is also considered a confined space. The OSHA office in each jurisdiction should be consulted for additional regulations.

4.9.2 *Fall protection*—Fall protection is also addressed by OSHA. A safety plan approved by each local OSHA inspector is important, and should include a company policy regarding fall protection.

CHAPTER 5—SLABS

The word "slab" refers to several distinct uses of a horizontal flat concrete element. The document on concrete terminology, ACI 116R, defines a slab as "a molded layer of plain or reinforced concrete, flat, horizontal (or nearly so), usually of uniform but sometimes of variable thickness, either on the ground or supported by beams, columns, walls, or other framework." Concrete slabs can be elevated (spanning between isolated supports such as columns or walls), or cast on the ground. Slabs in residential construction are generally cast on the ground, and are commonly called slabs-on-ground. Residential slabs-on-ground can be structural or nonstructural, depending on whether or not they are a required part of the structural load path that transmits vertical lateral building loads to the soil.

5.1—Slabs-on-ground

Nonstructural slabs-on-ground are slabs cast on the ground that are not a required part of the structural load path transmitting vertical or lateral building loads to the ground. Nonstructural slabs-on-ground can be inside or outside the building footprint. When they are outside of the building footprint, they are often called flatwork or site concrete, and include sidewalks, driveway slabs, carport slabs, or patio slabs. Nonstructural slabs-on-ground inside the residential building footprint are those that are located between or above footings (either continuous wall footings or pad footings under posts). The footings are designed to transmit all framing loads from the upper floors and the roof to the ground. In addition, nonstructural slabs-on-ground are not required by design to carry any lateral loads (seismic or wind) to the soil. In those cases, all lateral loads (shears and overturning moments) are transferred to the ground through the footings without a required contribution from the slab. Nonstructural slabs-on-ground can be cast monolithically with footings, or they may be cast as a different element with a construction joint. A thickened slab or integral footing may be used beneath interior bearing walls to transmit load to the soil. Interior nonstructural slabs transmit to the soil only their own weight, live loads (such as furniture, foot traffic, and surfaces) applied directly (without framing from above) to the slab surface, and dead load from nonbearing partition walls. Nonstructural slabs-on-ground can be unreinforced, or they may contain reinforcement for resisting the effects of shrinkage and temperature.

Structural slabs-on-ground are slabs cast on the ground that serve some code-required structural function in the load path transmitting vertical and lateral building loads from the superstructure to the ground. Examples of structural slabs-on-ground include slabs that are designed to span between isolated supports, such as piles, ignoring soil support; slabs that support bearing walls or post loads carrying framing loads from the roof or floors above and transmitting those loads directly to the ground without footings; slabs that are required by design to transmit seismic or wind shears to the soil as a horizontal diaphragm; and slabs that resist or span over volume changes in expansive soils. Structural slabs-on-ground can be designed as either structural plain concrete or as reinforced concrete in accordance with the appropriate criteria for those categories of structural concrete as specified in ACI 318. Information regarding the design of structural slabs-on-ground can be found in ACI 360R, 302.1R, *Design of Post-Tensioned Slabs-on-Ground* (Post-Tensioning Institute 2004), and *Design of Slab-on-Ground Foundations* (Wire Reinforcement Institute 2003a).

Structural slabs-on-ground may be unreinforced if they are designed as structural plain concrete. The presence of any amount of prestressed or nonprestressed reinforcement does not prohibit the slab from being classified as plain concrete if all requirements for plain concrete members are satisfied in accordance with Chapter 22 of ACI 318. If designed as reinforced concrete, the slab should contain at least the minimum amount of prestressed reinforcement, nonprestressed reinforcement, or both, required by ACI 318 to qualify as a reinforced concrete slab.

5.1.1 *Subgrade*—To address the need of uniform slab support, anything that would result in nonuniform support of the slab is to be removed from the soil below. Grass, sod, roots, and other organic matter should be removed. Utility trenches and holes should be filled and properly compacted using fill material uniform in composition and free of organic matter, large stones, or large lumps of frozen soil. The subgrade should also be well drained and properly graded to prevent soil erosion, ponding of water, or continual saturation of soil under the slab such that the soil cannot support the loads applied to the slab. The IRC addresses these issues by requiring surface drainage to be diverted to a storm sewer or other point of collection and the surface to be graded so as to drain surface water away from the foundation walls.

5.1.2 *Subbase*—Where the bearing support or grade is not uniform, especially in clay or other cohesive soils, it is desirable to install a subbase of granular fill such as sand, crushed stone, or gravel 4 to 6 in. (100 to 150 mm) thick. Cinders or clay should not be used because they will not give firm and uniform support. The subbase should be uniform in thickness and well compacted. The IRC requires that a 4 in. (100 mm) thick base course of clean graded sand, gravel, crushed stone, or crushed blast-furnace slag be placed under the slab-on-ground when the slab is below ground, such as a basement slab.

5.1.3 *Vapor retarder*—A vapor retarder is placed above any granular layer and under the slab-on-ground to minimize the transmission of water vapor into the occupied space above. Membrane materials, when tested by ASTM E 96, with a permeance of less than 0.3 US perms (0.2 metric perms) are recommended. Polyethylene film is commonly used, and a minimum thickness of 10 mils (0.25 mm) is recommended (much more durable against puncture during construction/placement operations) for reduced vapor transmission and durability. The IRC requires a vapor retarder be placed above any granular layer and under the slab-on-ground where the space above is enclosed and heated. There are three exceptions to this requirement. The first exception is where the use of the building is an unheated accessory structure such as detached garage or utility shed. The second exception is where the slab is for driveways, patios, and sidewalks and not likely to be enclosed at a later date. The third exception to this requirement is left to the code officials' discretion based on "local site condition." Examples of local site condition could be a site located in a desert or where there is a combination of granular soil and a low water table. More information on concrete slab moisture and vapor retarders under slabs-on-ground can be found in NRMCA CIP 28 and 29.

5.1.4 *Special soils*—A licensed geotechnical engineer should be consulted where highly compressible soils (soils that have liquid limit values greater than 50%) or expansive or unstable soils (soils with a plasticity index greater than 15) are encountered. These soil conditions make it possible for a floor slab to heave, settle, or sink over time. Directed modifications could involve, for example, removal of the existing soil to depths of 12 in. (300 mm) or more below the slab and replacement with granular fill to reduce pressures on the lower and softer soils unless the design of the foundation accounts for the adverse soil conditions. Refer to references from the Post-Tensioning Institute (2004) and the Wire Reinforcement Institute (2003a) for design recommendations for slabs built on expansive soils.

5.1.5 *Formwork*—Forms for residential concrete slabs are usually made of wood; however, other materials that will maintain the desired shape and dimension of the slab may be used. Before each use, they should be cleaned and coated with a release agent. Blockouts, inserts, and embedded items should be properly identified, positioned, and secured before concrete placement. Forms should be braced to hold alignment, elevation, and plumbness during placement. They may be removed when the concrete has stiffened enough to maintain its shape and the edges are not damaged by the removal method.

5.1.6 *Reinforcement for shrinkage and temperature*—Reinforcement intended to resist stresses produced by shrinkage and temperature effects can consist of deformed bars, post-tensioned tendons, welded-wire reinforcement, and synthetic or steel fibers.

5.1.6.1 *Deformed bars*—For slabs-on-ground where the number of control joints is to be minimized (or the spacing maximized) and the width of any crack held to a minimum, steel reinforcing bars can be used. Deformed reinforcing steel 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. ACI 302.1R recommends that reinforcement be positioned within the top one-third of the slab depth.

5.1.6.2 *Welded-wire reinforcement*—For slabs in which the layout precludes the proper spacing of control joints or where the use of the slab may dictate fewer joints, welded-wire fabric may be used to reduce crack width. Light-gauge welded-wire fabric does not, however, significantly increase the flexural strength or the load-carrying capacity of the slab. The Wire Reinforcement Institute's (WRI) TF 702-R-03 (Wire Reinforcement Institute 2003b) and ACI 302.1R recommend that welded-wire reinforcement be placed 2 in. (50 mm) below the slab surface or within the upper third of the slab thickness, whichever is closer to the surface. Reinforcement should extend to within 2 in. (50 mm) of the slab side edge. Due to the flexibility of welded-wire reinforcement, the contractor should pay close attention to establishing and maintaining adequate support of the reinforcement during 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 (wet setting) after placing the concrete.

For placing purposes, a welded-wire fabric in sheet form is preferred to welded-wire fabric in rolls because the sheet form is safer and easier to use and hold in position.

5.1.6.3 *Synthetic fibers*—Synthetic fibers are usually made of polypropylene or nylon. They are generally either fibrillated or monofilament design. Fibrillated fibers are contained in small bundles of interconnected fibers that open up and disperse during mixing. Monofilament fibers are individual, smooth, round fibers.

Synthetic fibers are added to the concrete during mixing and become distributed throughout the concrete before placement. Fibers provide resistance to plastic shrinkage cracking and improve abrasion resistance. Additional information on synthetic fibers can be found in NRMCA CIP 24.

5.1.6.4 *Steel fibers*—Steel fibers are recognized for improving the hardened concrete's impact resistance, flexural fatigue endurance, ductility, spalling resistance, shrinkage, and temperature crack control and crack propagation resistance as well as beam shear strength, punching shear, and anchor bolt pullout. Steel fiber varies in length vary from 1/2 to 2-1/2 in. (13 to 65 mm), as well as in diameter, which varies from 0.017 to 0.04 in. (0.45 to 1.0 mm). Steel fibers are available in round, oval, rectangular, and crescent cross sections. For dosage rates of a particular fiber, the manufacturer's instructions should be consulted.

5.2—Elevated slabs

Elevated slabs are structural slabs that span between isolated supports, typically columns, beams, or walls. They can be categorized generally as one-way and two-way slabs, depending on the layout and orientation of their supports. One-way slabs have continuous supports, such as beams or wall, and thus resist bending in one direction only. Two-way slabs span between isolated point supports, such as columns, and thus resist bending in two orthogonal directions. Two-way slabs can be built with a solid thickness throughout (no beams or dropped sections), in which case they are called flat plates. Two-way slabs can also be built with thickened sections over the columns; these are called drop caps or drop panels. Elevated slabs are rare in residential construction, but they do occur occasionally, primarily over basement areas. The design of two-way slabs should always be executed by a licensed design professional. For reference purposes, refer to the *CRSI Design Handbook* (Concrete Reinforcing Steel Institute 2002) or ACI 318.

5.2.1 *Reinforcement*—Reinforcement used in elevated slabs can be prestressed or nonprestressed. Nonprestressed reinforcement generally consists of deformed reinforcing bars conforming to ASTM A 615. Prestressed reinforcement generally consists of unbonded post-tensioned tendons conforming to the requirements of "Specification for Unbonded Single Strand Tendons" (Post-Tensioning Institute 2000). Prestressing steel used in unbonded tendons is usually 1/2 in. (13 mm) diameter, seven-wire strand conforming to ASTM A 416.

5.3—Concrete

Concrete properties for residential slabs vary depending on the use and exposure of the slab. The required strength may range from 2500 to 4500 psi (17 to 31 MPa). Slump at time of placement is generally 3 to 5 in. (75 to 125 mm). Refer to Chapter 2 for complete information on material and concrete properties.

Fig. 5.1—Common shovel ideal for spreading concrete.

Fig. 5.2—Mechanical strike-off (photo courtesy of J.D. Honigberg International).

5.4—Placing and finishing

5.4.1 *Placing*—It is important that the subgrade is compacted, trimmed, and moistened, the forms are properly erected, and the reinforcing steel and other embedded items are set securely in place before placing the concrete. The concrete should be discharged and placed as near as possible to its final position, proceeding in a direction toward the point of discharge. Concrete should not be placed faster than the screeding (strikeoff) process can be performed. The placing operations level, shape, and smooth the concrete surface while working up a slight amount of cementitious paste. The operation includes spreading, screeding using a straightedge, and leveling by either darbying or bullfloating. Darbying or bullfloating should be completed before bleed water begins to collect on the surface. The size of the finishing crew should be planned with regard for the effects of temperature and humidity on the rate of hardening of the concrete.

Spreading the concrete should be done with a short-handled, square-end shovel (Fig. 5.1) or a specifically designed hoe-like tool. Screeding or strike-off cuts off excess concrete to bring the top surface of a slab to the proper grade using a straightedge. Darbying or bullfloating eliminates high and low spots and embeds large aggregate particles; this process should be used immediately after strike-off. Vibrators should not be used to spread concrete.

Reinforcing steel and welded-wire reinforcement should be supported and tied together sufficiently to minimize movement during concrete placing and finishing operations.

Fig. 5.3—Hand strike-off.

Chairs with sand plates or precast-concrete bar supports are generally considered to be the most effective method of providing the required support.

5.4.2 *Consolidation*—Consolidation, also called compaction, is a process that reduces entrapped air voids in the concrete mixture and brings the solid particles closer together. During consolidation, concrete should be worked around reinforcement and embedded fixtures and into corners of the forms. Vibrating, spading, and other manual and mechanical ways are used to achieve consolidation. The method chosen depends on the consistency of the mixture and the complexity of formwork and reinforcement.

5.4.3 *Strike-off*—Striking off, commonly called screeding, involves moving a straightedge, supported by a truss, frame, or form, back and forth along the surface. This evens off the surface to a specified elevation. Strike-offs (Fig. 5.2) are commonly used on large areas. Striking off can be performed by hand (Fig. 5.3), and should be done immediately after placement.

5.4.4 *Bullfloating and darbying*—A darby or bullfloat is used to smooth out ridges, fill voids left by the straightedge, and slightly embed the coarse aggregate. Darbies (Fig. 5.4) have limited reach and are used near the edge of slabs or in confined areas. Bullfloats (Fig. 5.5), by virtue of their long handle, are more commonly used on most slabs. Darbying or bullfloating prepares the surface for future finishing operations.

5.4.5 *Bleeding*—It is usually necessary to wait for the bleed water to collect, then evaporate from, the concrete surface before further finishing operations can be started. No finishing operations should take place with bleed water on the surface, as this leads to dusting, scaling, and other surface defects. Finishing operations can usually resume when the concrete has stiffened enough to support foot pressure with only about a 1/4 in. (6 mm) indentation.

Fig. 5.4—Darbying.

5.4.6 *Edging*—The purpose of edging (Fig. 5.6) is to make the edges of slabs slightly rounded and less likely to chip under traffic or when the forms are removed. Before using the edger, a pointed trowel (with a vertical sawing action) should be used to dislodge the concrete from the side form so that the edger is less likely to dig in or leave a bumpy surface. Edging should take place after each floating operation. Edges should not be rounded on a floor to be covered with tile.

5.4.7 *Floating*—After waiting for the bleed water to evaporate from the surface, floating can begin. Floating embeds large aggregate just below the surface; removes slight imperfections, humps, and surface voids; compacts the concrete; and re-opens the surface for drying. It may be done by hand or with a machine equipped with float blades.

Floating consolidates mortar at the surface of the concrete where it is needed for the next step in finishing and troweling. Floating should always be performed if the concrete will be troweled. Exterior slabs, such as driveways, may be floated and not troweled. Troweling such slabs will reduce traction and may result in poor durability under freezing-and-thawing exposure due to reduced air content at the surface.

5.4.8 *Troweling*—Troweling produces a smooth, hard surface. It may be done by hand (Fig. 5.7) or by machines equipped with trowel blades (Fig. 5.8). Troweling should begin immediately after floating. If done by hand, the finisher should float and trowel one area, and then move to the adjacent area.

The surface of the trowel blade should be kept as flat against the concrete surface as possible. A trowel blade held at an angle to the surface will produce a washboard, or chatter, appearance. An older trowel that has been broken in will work better for the first troweling.

Additional trowelings may take place as the concrete stiffens if it is desired to make the surface denser and smoother. Smaller trowels, held at an increasing angle to the surface, should be used for this purpose. Additional hard troweling for exterior concrete is discouraged because it can result in decreased air content at the surface with a corresponding reduction in freezing-and-thawing durability. One pass of steel troweling is usually sufficient for interior residential slabs.

Fig. 5.5—Bullfloating.

Fig. 5.6—Edging concrete slab.

Fig. 5.7—Hand troweling.

5.4.9 *Brooming*—Brooming provides a textured, slip-resistant finish. It is done by lightly drawing a broom over the concrete surface. It may be done after floating or troweling. A variety of textures can be achieved depending on the type of broom used.

NRMCA (CIP 14) and ACI (302.1R and CCS-1) present guidelines on finishing concrete flatwork in CIP 14.

5.5—Jointing

Joints in concrete slabs minimize uncontrolled cracking by accommodating differential movement of adjacent

Fig. 5.8—Machine troweling.

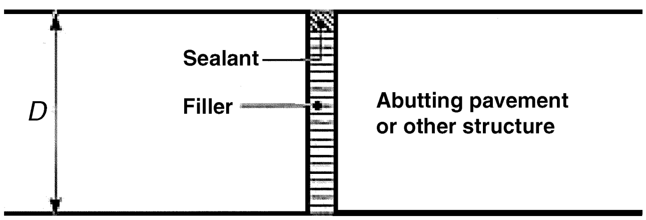

Fig. 5.9—Free isolation joint (photo courtesy of Cement & Concrete Association of New Zealand).

Fig. 5.10—Slab joints predetermine crack locations (photo courtesy of Portland Cement Association).

elements of construction, providing natural planes of weakness, and preventing undesirable bonding to adjacent elements. Three types of joints are used in concrete slabs: isolation joints; contraction joints; and construction joints. NRMCA has additional information on joints in concrete slabs-on-ground in CIP 6.

5.5.1 *Isolation joints*—Isolation joints, sometimes called expansion joints, provide freedom of movement between the concrete slab and adjacent building elements (Fig. 5.9). They should be used at interfaces with walls, columns, footings, stairway supports, and other locations where separation is

Fig. 5.11—Hand-grooving a contraction joint.

intended to reduce restraint to movement between two elements. Isolation joints, however, are not always used in basements and other interior slabs due to radon and structural considerations. The joint is formed by inserting preformed joint material between the floor and the adjacent element before concreting. It should extend the full depth of the slab and not protrude above it. Where required, a flexible sealer may be used to finish the joint above the filler material.

5.5.2 *Contraction joints*—Contraction joints, sometimes called control joints, accommodate movements that are caused by temperature changes, drying shrinkage, and creep. The joint is sawed (Fig. 5.10), formed, or tooled (Fig. 5.11) part way through the depth of the concrete to form a weakened plane that encourages thermal-shrinkage cracks to occur at a predetermined line and not at random locations. In a 4 in. (100 mm) thick residential slab-on-ground, contraction joints should be located not more than 10 ft (3 m) apart in both directions. It is recommended that joint spacing be limited to a maximum of 15 ft (4.5 m.). A shorter interval can be used when necessary. To determine the joint spacing, the maximum distance should be 24 to 36 times the thickness of the slab in feet.

Contraction joints may be formed by tooling, sawing (Fig. 5.12 and 5.13), or using plastic divider strips. Joints should produce a vertical groove at least 1/4 the thickness of the slab, but not less than 1 in. (25 mm) deep. Early-entry dry-cut or soft-cut joints are generally run 1 to 4 hours after completion of finishing, depending on the concrete's setting characteristics. These joints are typically not as deep as those obtained by the conventional sawcut process, but should be a minimum of 1 in. (25 mm) in depth. Drying shrinkage may cause unwanted cracks to develop before sawing. Therefore, sawing should begin as soon as the concrete is capable of supporting the saw, usually within 4 to 12 hours after the concrete has been finished.

5.5.3 *Construction joints*—Construction joints are full-depth separations in slabs introduced for the convenience of construction. They are usually located where one placement ends and the next begins. They may be required if the concrete placement is interrupted.

Fig. 5.12—Dry sawing (photo courtesy of Portland Cement Association).

Fig. 5.13—Wet sawing (photo courtesy of Soff-Cut International).

Fig. 5.14—Burlap curling (photo courtesy of Portland Cement Association).

5.6—Curing

Curing is the maintaining of a satisfactory moisture content and temperature in concrete. Curing begins after placement and continues after finishing so that the concrete may develop the desired strength and durability (NRMCA CIP 11). Refer to ACI 308R for specific procedures and recommendations for curing.

Curing is an important part of the concrete construction process. The desirable properties of concrete, such as strength, water tightness, durability, and wear resistance, are enhanced by proper curing. To reach its highest strength, concrete should be kept from drying as long as possible. Normally, when concrete is placed, it contains more water than is needed for complete hydration. Evaporation may reduce the retained water below that needed for development of desired properties. The curing period should be as long as practical. The period of time that the concrete should be cured depends on the type of cement, mixture proportions, required strength, size and shape of the slab, ambient temperature, and future exposure conditions. The length of curing for ambient temperatures above 40 °F (4 °C) should be a minimum of 7 days or the time necessary to attain 70% of the specified compressive or flexural strength. Adequate moisture can be ensured by using the materials and methods listed in Sections 5.6.1 through 5.6.3.

5.6.1 *Coverings*—Burlap, cotton mats, or other fabrics kept continuously wet provide excellent curing conditions (Fig. 5.14). Waterproof paper and polyethylene sheets are good moisture retarders, but both may produce surface mottling or discoloration.

5.6.2 *Curing compounds*—The use of a spray-on, roll-on, or brush-on membrane-forming curing compound is probably the easiest, most economical, and convenient way to cure concrete. The liquid curing compounds should be applied as soon as final finishing is completed. Application rate and method should be per manufacturer's recommendations.

5.6.3 *Ponding*—Ponding is another method of curing. Typically, earthen or sand dikes are built around the edges of the slab. The slab is then flooded with water for 3 to 7 days. The water should not be more than 20 °F (11 °C) cooler than the concrete, and the dike or barrier that holds the water should be secure against leaks to prevent wetting and drying during the curing period.

CHAPTER 6—PROJECT CONSIDERATIONS

6.1—Ordering ready mixed concrete

Orders for ready mixed concrete for residential applications should include the following information:

- Type of mixture application (such as flatwork or formed walls), or both;
- Specified strength, cement type, maximum aggregate size, permissible water hold-back, and any other concrete material proportioning criteria shown on the contract documents;
- Date requested;
- Location of site, with cross streets;
- Placement type (such as pumped, from the chute, and wheelbarrow);
- Desired or specified slump;
- Any special needs (such as color, fibers, and special cements); and
- Proper approvals and inspections should be obtained, scheduled, or both.

NRMCA CIP 31 provides some additional guidelines on ordering ready mixed concrete.

Fig. 6.1—Consequences of getting too close.

6.2—Site considerations

6.2.1 *Access*—Concrete placement requires heavy equipment to deliver materials to the site. Concrete trucks can exert extremely heavy loads on soil or subgrade during delivery. Precautions should be taken so that all site access routes can carry the imposed loads. Soft soils, wet subgrades, or both, without proper preparation may not sufficiently support the concrete truck, and can cause delays in construction (Fig. 6.1). Access roads should be as level as possible and perpendicular to the front and rear of the truck to help prevent rollovers. If in doubt, the contractor or concrete supplier can assist in determining if access is adequate.

A typical concrete truck is 12 ft (3.7 m) high, 8 ft (2.4 m) wide, 28 ft (8.5 m) long and, fully loaded, weighs in excess of 60,000 lb (27,000 kg). If access is restrained due to height, width, or tight turns, other placement methods should be used.

6.2.2 *Damage prevention*—Due to the heavy loads imposed by a concrete truck, delivery traffic over existing concrete, utilities, septic tanks, and landscape materials should be avoided whenever possible. When this is not possible or is impractical, precautions should be taken to spread the load across a larger area:

- Use lumber or timbers at the edge of any concrete flatwork to transfer the load off the edge (particularly curbs and sidewalks that should be supported on both sides creating a ramp over the material);
- Keep heavy vehicles off any thin sections of concrete to prevent cracking;
- Do not allow a concrete truck within a distance equal to 1 ft/ft (1 m/m) of depth of any excavation; and
- Identify any drains or shallow grade utilities that could be damaged and provide support over them.

6.3—Placement considerations

6.3.1 *Preplacement*—All tools and equipment that will be needed should be checked to ensure that they are working and readily available before placing concrete. Backup equipment should be readily available to prevent cold joints or other defects in the event of mechanical breakdown or power failure. For walls, all forms should be plumb, firmly fastened, and coated with releasing agent. Inspections should be completed with the proper approvals.

6.3.2 *Proper placement*—It should be ensured that, during placement, no foreign matter, such as dirt or clay, works into the fresh concrete from the workers' work boots. Also during placement, especially with pumps, caution should be taken so that the sub-base material does not boil up into the fresh concrete due to the force of the pump.

6.3.3 *Finishing considerations*—Improper finishing is the cause of a number of concrete problems, and the methods described in Chapter 5 should be followed. For further information and guidelines, refer to NRMCA CIP 14.

6.3.4 *Chute wash-down*—The homebuilder should provide a place for the concrete truck driver to wash the truck chutes after placement. This should be a location that will be filled in or covered sufficiently so as to not affect other aspects of the building site, such as landscaping. If necessary, the wash-down material may have to be hauled away. Typically, not more than 20 gal. (75 L) of water from the truck is used for this process.

6.4—Special materials

6.4.1 *Colored concrete*—Colored concrete can be produced by using colored aggregates, adding color pigments (ASTM C 979), or both.

6.4.1.1 *Exposed aggregate coloring*—Colored aggregates may be natural aggregates such as quartz, marble, and granite, or be manufactured, such as ceramic materials. When colored aggregates are used, they can be either integrated into the concrete mixture or worked into the surface after screeding. In both cases, some means of removing the paste coating on the aggregate surface should be planned. One method used is to spray a retarder on the surface after finishing to prevent it from setting while the rest of the concrete sets. The unhydrated paste at the surface is later brushed and washed away, leaving the aggregates exposed. Other methods involve removing the surface mortar by sandblasting, waterblasting, bushhammering, grinding, or acid washing. These methods are more aggressive and usually involve specialized equipment and knowledge in their application.

6.4.1.2 *Integral color pigments*—Pigments for concrete should be pure mineral oxides ground finer than cement and be insoluble in water, free of soluble salts and acids, colorfast in sunlight, resistant to alkalis and weak acids, and virtually free of calcium sulfate. Mineral oxides occur in nature, and are also produced synthetically. Synthetic pigments generally give more uniform results. The amount of color pigments added to a concrete mixture should not be more than 10% of the weight of the cement. The amount required depends on the type of pigment and color desired. Variations in cements and aggregates can cause changes in the tints of concrete. The use of pigments in a concrete mixture may require adjustments in mixture proportions or admixture dosage to maintain workability and durability.

6.4.1.3 *Surface color pigments*—Slabs and precast panels that are cast horizontally can be colored by the dry-shake method. Dry coloring materials consisting of mineral oxide pigment, white cement, and specially graded silica sand or other fine aggregate is marketed ready for use by various manufacturers. After the slab has been floated once, 2/3 of the dry coloring is broadcast evenly over the surface and floated in. Immediately after, the rest of the material should be applied at right angles to the initial application and floated in. Other finishing operations follow, depending on the type of finish desired.

Staining the surface has also been used quite successfully in coloring existing hardened concrete. Manufacturer's recommendations should be followed when using any coloring agents.

6.4.1.4 *Textured concrete*—Concrete, as a plastic material, will take on any shape it is formed against or that is stamped into it. Many new textures for stamping and forming concrete are on the market today. It is important to follow all the manufacturer's recommendations regarding release agents when using these systems.

6.4.2 *Architectural concrete*—Concrete is a natural material and subject to variations in coloring and texture. Because of this, expectations regarding architectural finishes and colors should be agreed on between all parties before concrete placement. When color and texture are critical, a test panel or mockup section should be cast and left on the project site for ease of reference. The architect should determine the specified distance and time at which the acceptance of the color should be judged after the panel has been cast. Efforts should be made to complete concrete placements to an architectural break in any one period of placement to minimize the likelihood of discoloration.

6.4.3 *Deicers*—Deicing chemicals for snow and ice removal from concrete are typically salts, such as sodium chloride and calcium chloride. When placed on ice, these salts lower the freezing point of the water, thereby allowing the ice to melt at a lower temperature than normal. The resulting water with dissolved salts is then absorbed into the pores of the concrete surface. The salts build up osmotic and hydraulic pressures in excess of normal pressures when water in concrete freezes, resulting in a scaled surface. A secondary mechanism, salt recrystallization upon drying, can also aggravate scaling.

Ideally, deicing agents, such as sodium chloride and calcium chloride, should be avoided before the first year after placement. If deicing chemicals must be used, the best protection is to place air-entrained concrete and seal the surface with a high-quality sealer applied per the manufacturer's recommendations to prevent as much water penetration as possible. The use of clean sand for traction is a good practice. When possible, the concrete surface should be washed with water in the spring to prevent salt buildup. Ammonium sulfate or ammonium nitrate should never be used as a deicers; these are chemically aggressive and destroy concrete surfaces.

6.4.4 *Sealers*—Clear coatings are frequently used on concrete surfaces to prevent soiling or discoloration of the concrete by air pollution, facilitate cleaning the surface if it becomes dirty, brighten the color of the aggregates, and render the surface water-repellent, reducing color change due to water absorption. A number of clear and colored sealants are available on the market today. Before applying a sealer to concrete, the concrete should be allowed to dry out sufficiently.

6.5—Hot weather concreting

Before concrete is placed, certain precautions should be taken during hot weather to maintain or reduce concrete temperature. Forms, reinforcing steel, and subgrade should be fogged or sprinkled with cool water just before the concrete is placed. Fogging the area 5 ft (1.5 m) above the fresh concrete during placement and finishing operations cools the contact surfaces and surrounding air and increases the relative humidity. This reduces the temperature rise of the concrete and minimizes the rate of evaporation of water from the concrete after placement. There should be no standing water or puddles on forms or subgrade at the time concrete is placed. ACI 305R contains more information on hot weather concreting. NRMCA provides additional guidelines on hot weather concreting in CIP 12.

6.6—Cold weather concreting

Concrete can be effectively placed throughout the winter months in cold climates when adequate protective measures are taken. Success under these conditions is based on several key factors, including proper air entrainment, control of the concrete temperature, *w/cm*, moderate placement temperatures, proper concrete mixture proportion, and protective measures such as blankets and portable heaters. When the mean daily ambient temperature drops below 40 °F (4 °C) for more than three successive days, certain precautions need to be taken. ACI 306R gives two sets of tables and graphs showing required resistance to heat transfer (*R*) of insulating blankets that may be required in extreme temperature conditions to protect the concrete temperatures from dropping below freezing (27 °F [–3 °C] for normal concrete) before reaching 500 psi (3.5 MPa). The data extends to a protection period of 1 week and states that insulating blankets should be supplemented with heat for slabs 12 in. (300 mm) or less in thickness. Other ACI 306R cold weather concreting practices should be followed.

Cold weather concrete is often controlled by the perception of the ambient temperature. An important factor in the performance of concrete in cold weather is air entrainment. The most important factor affecting the performance of concrete during these conditions, however, is the concrete temperature. Concrete temperature is affected by the hydration timing of the mixture and the ambient temperature. Depending on the proportions of the mixture and the temperature curve achieved, the strength of the concrete can be effectively predicted using maturity methods that will provide the information necessary as to the appropriate time to remove additional protective systems and forms and finishing with backfill. Key planning and placement steps, as discussed in the "Cold Weather Research Report" (Concrete Foundations Association 2004), can dramatically affect the maintenance of higher curing temperatures in the concrete.

ICF systems also are effective at maintaining higher internal concrete temperatures, leading to improved strength gain.

The proportions of the concrete mixture is one of the keys to successful cold weather concreting. By varying cement content and type, adding calcium or a nonchloride admixture, and controlling the temperature at the time of mixing, the success of this mixture can be ensured. Other than air entrainment, the concrete temperature and *w/cm* are very important factors affecting the ability of the mixture to reach the proper hydration temperature and attained strength before freezing. Excessive water in the mixture (sometimes occurring by job site water additions) will prevent the absorption of the free water in the mixture during hydration and increase the likelihood for frost and freezing within the mixture from a higher coefficient of thermal transfer. The concrete producer should follow the mixture proportions. Any increase in the workability of the mixture that may be desired should be achieved with water-reducing admixtures rather than water.

During extreme cold weather conditions, preparations should be made to protect the concrete. This is achieved with blankets, insulated forms, windbreaks, enclosures, and portable heaters. These protective measures should be on site and ready to implement as soon as finishing is completed and as long as placement of the protection does not damage the finished surface.

Preparation for placement of the concrete includes checking the forms, reinforcement, and embedded fixtures as they should be clear of snow and ice at the time of placement. Caution should be taken not to place concrete on frozen subgrades because when it thaws, uneven settlement may occur and cause cracking. For more information, refer to the "Cold Weather Research Report" (Concrete Foundations Association 2004) or ACI 306R. NRMCA provides some additional guidelines on cold weather concreting in CIP 27.

6.7—Troubleshooting

As with any material, concrete not properly mixed, placed, finished, and cured can experience a number of potential problems. Troubleshooting these problems should be left to the experienced concrete professional. Additional information on specific concrete-related problems can be obtained through ACI, PCA, and the NRMCA. Typical concrete-related problems in residential construction are cracking, scaling, blisters, popouts, dusting, and discoloration.

6.7.1 *Cracking*—There are two basic explanations for concrete cracking: stress due to applied loads, and stress due to drying shrinkage or temperature changes in restrained concrete. When provisions for these movements are not made in construction, the stresses are relieved through cracks. Cracking can be significantly reduced when the causes are understood and preventative steps are taken. Because concrete (plain or reinforced) does crack and cracking cannot always be avoided, shrinkage crack widths up to 1/8 in. (3 mm) should be considered normal and acceptable (tolerable). ACI 224R provides some guidance on acceptable flexural crack widths. NRMCA provides some guidelines on cracking in CIP 4.

6.7.1.1 *Shrinkage/temperature cracking*—The amount of drying shrinkage will be reduced by taking practical measures such as placement of the concrete with the lowest possible water content. The amount of thermal cracking can be reduced by proper jointing during times of large temperature swings (±30 °F [±17 °C]). Some of the following practices contribute to restraint cracking:

- Contraction joints not sawn early enough;
- Contraction joints not deep enough;
- Contraction joints spaced too far apart;
- Slabs strongly restrained at their perimeter by bond of the slab concrete to foundation walls or other construction;
- Omission of joints or extra reinforcement placed diagonally to re-entrant corners;
- Placement of concrete with excessive water;
- Deficient or no curing;
- Slabs restrained by a rutted or uneven base, and changes in slab thickness;
- Reinforcement continuously through joints preventing movement; and
- Casting slabs upon a base that has a high coefficient of friction.

6.7.1.2 *Plastic shrinkage cracks*—Plastic shrinkage cracks are relatively short, shallow, random (but sometimes parallel) cracks that occur before the final finishing on days when wind, low humidity, and high concrete and ambient temperatures occur. Surface moisture evaporates faster than it can be replaced by rising bleed water, causing the surface to shrink more than the interior concrete. As the interior concrete restrains shrinkage of the surface concrete, stresses that exceed the concrete's tensile strength develop, resulting in surface cracks. Refer to Fig. 6.2 as an example of these cracks. NRMCA provides some additional guidelines to reduce plastic shrinkage cracks in CIP 5.

Some helpful measures to reduce plastic shrinkage cracking are:

- Dampening the subgrade before placement;
- Erecting windbreaks;
- Erecting sunshades;
- Using cool concrete;.
- Preventing rapid drying;
- Avoiding the use of vapor retarder where not required;
- Reducing the *w/cm*; and
- Curing concrete as soon as possible.

The setting time of the concrete influences the extent of this cracking during these conditions. By accelerating the setting time of the concrete using accelerating water-reducers in high evaporation or low bleed water situations, plastic shrinkage cracking can be avoided. Using cool concrete, although lowering the hydration rate of the concrete, can cause slab crusting if not properly managed.

6.7.1.3 *Crazing cracks*—Crazing, a pattern of fine cracks that do not penetrate much below the surface, is caused by minor surface shrinkage. Crazing cracks are very fine and barely visible except when concrete is drying after the surface has been wet. They are similar to mud cracking in shape and generation. The term "map cracking" is often used to refer to cracks similar to crazing, only more visible and involving larger areas of concrete. Although crazing cracks can be unsightly and can collect dirt, crazing is not structurally serious, and does not necessarily indicate the start of future deterioration in interior slabs. To prevent crazing, curing procedures should begin immediately—within minutes after final finishing, particularly after hard troweling. NRMCA provides additional guidelines on crazing cracks in CIP 3.

Other precautions should include:

- Avoiding curing with water that is more than 20 °F (11 °C) cooler than concrete;
- Avoiding alternate wetting and drying of surface at early ages;
- Exercising care when using jitterbugs, vibrating screeds, and bullfloats for compaction. The surface should not be overworked, which brings excessive mortars to the surface;
- Not overworking the surface;
- Avoiding premature floating and troweling of surface;
- Not dusting cement onto the surface for drying;
- Limiting the amount of clay or dirt in the aggregates to a maximum 3.0% by mass per ASTM C 33; and
- Not sprinkling water onto the surface during finishing.

6.7.1.4 *Other causes of cracks*—Cracking can result from other causes:

- Settlement due to uneven support by poorly prepared subgrades;
- Movement due to placement on expansive clays or soils with inconsistent moisture content;
- Structural overloading, including: impact loads, early or excessive construction traffic, and earth movements from contiguous construction; and
- Improper design, resulting in a slab structure inadequate for the service conditions.

6.7.2 *Dusting*—Dusting occurs due to a weak concrete surface of a floor or slab. Dusting is the development of a fine powdery material that easily rubs off the surface of hardened concrete. It can occur either indoors or outdoors, but is most likely a problem when it happens indoors. The presence of carbon monoxide and carbon dioxide, which chemically react with the slab surface during finishing operations, is often the cause of indoor slab dusting. Dusting is a result of a thin, weak surface layer, called laitance, which is composed of water, cement, and fine particles. One of the key causes to dusting is the floating of bleed water back into the surface, further reducing the strength and wear resistance of the surface concrete. NRMCA provides some additional guidelines on dusting in CIP 3.

Dusting can also be caused by:

- Overly wet mixtures with poor finishing characteristics;
- Insufficient cement;
- Clay and dirt in the aggregate;
- Use of dry cement spread on the surface during finishing;
- Water applied to the surface during finishing;
- Inadequate curing;
- Inadequate air-drying; and
- Freezing of the surface.

Fig. 6.2—Plastic shrinkage cracking of concrete surface (photo courtesy of National Ready Mixed Concrete Association).

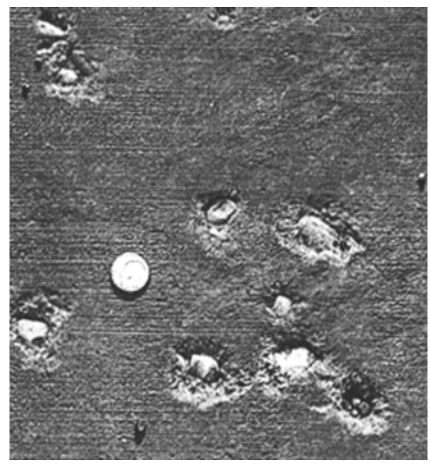

Fig. 6.3—Popouts from concrete slab.

6.7.3 *Scaling*—Scaling is the loss of surface mortar surrounding the coarse-aggregate particles. As a result, the aggregate is exposed, and often stands out from the concrete. Scaling is primarily a physical action caused by hydraulic pressure from water freezing within the concrete; it is not usually caused by a chemical corrosive action. NRMCA provides some additional guidelines on scaling in CIP 2.

The prominent causes of scaling include:

- Increased permeability of concrete due to poor-quality concrete;
- Concrete being exposed to freezing and thawing in service with little or no entrained air;
- Air content too low to resist the effects of deicer salts;
- Inadequate thermal protection at early ages; and
- Inadequate slope to properly drain water away from the surface.

6.7.4 *Popouts*—Popouts (Fig. 6.3) are roughly cone-shaped pits left in the surface of flatwork after a small piece of concrete has broken away due to internal pressure. This pressure is caused by the expansion of unsound materials such as a piece of chert, soft fine-grained limestone, shale, hard-burned lime, hard-burned dolomite, pyrite, or coal. In some of these materials, the expansion is caused by freezing

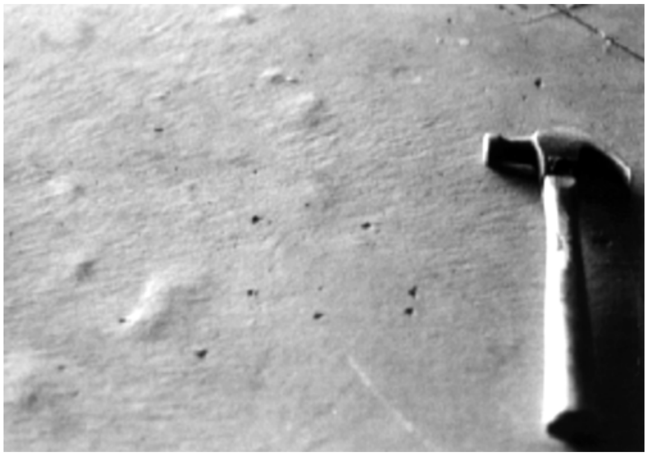

Fig. 6.4—Concrete surface with blisters (photo courtesy of National Ready Mixed Concrete Association).

or absorption of moisture, while in others, it is caused by a chemical change. Popouts range in size from 1/4 to 2 in. (6 to 50 mm) or more in diameter. Popouts do not usually significantly diminish the functionality of concrete flatwork. To repair popouts, the unsound aggregate particles should be removed from the concrete and the affected area patched. Popouts can be avoided by using sound, clean, nonreactive aggregates conforming to ASTM C 33 and C 330.

6.7.5 *Blisters*—The appearance of blisters (Fig. 6.4) on the surface of a concrete slab during finishing operations is annoying and an imperfection not easily repaired once the concrete hardens. These bumps can range in size from 1/4 to 4 in. (6 to 100 mm) in diameter with a depth of 1/8 in. (3 mm). They appear when bubbles of entrapped air or water rise through the plastic concrete and are trapped under an already sealed airtight surface. This closing of the surface often happens when the top of the slab stiffens, dries, or sets faster than the underlying concrete. NRMCA provides additional guidelines on blisters in CIP 13.

To avoid blisters, the following should be considered:

- Not attempting to finish the concrete before the concrete below has stiffened, the bleeding has stopped, and the concrete is firm enough to provide support;
- Avoiding slab placement over a saturated sub-base;
- Avoiding the use of concrete with excessively high slump, water content, air content, or fines;
- Using appropriate cement contents;
- Avoiding overworking the surface, especially with jitterbugs and floats; and
- Using a wooden float on non-air-entrained concrete to prevent early sealing.

6.7.6 *Discoloration*—ACI 302.1R states that surface discoloration of concrete flatwork can appear as gross color changes in large areas of concrete, as spotted or mottled light or dark blotches on the surface, or as early light patches of efflorescence. Like many other surface imperfections, discoloration is generally a cosmetic nuisance rather than a structural problem. NRMCA provides additional guidelines on discoloration in CIP 23. Factors found to influence discoloration are calcium chloride admixtures, concrete alkalis, hard-troweled surfaces, inadequate curing, variations in the *w/cm* at the surface, and changes in the concrete mixture.

Some of the typical causes for dark and light areas are:

- The use of calcium chloride in concrete can darken the surface due to delayed chemical reactions;
- Low spots where water stands longer can cause the appearance of darkening;
- Curing with waterproof paper sheets can cause dark and light spots;
- Changes in *w/cm* can significantly affect color;
- Uneven application of dry-shake materials and curing compounds can cause discoloration;
- Placing concrete at different times can cause discoloration due to differences in raw materials and placing conditions; and
- Incomplete mixing and uneven distribution of admixtures within the concrete can cause discoloration.

CHAPTER 7—REFERENCES

7.1—Referenced standards and reports

The standards and reports listed below were the latest editions at the time this document was prepared. Because these documents are revised frequently, the reader is advised to contact the proper sponsoring group if it is desired to refer to the latest version.

American Concrete Institute

116R	Cement and Concrete Terminology
117	Specifications for Tolerances for Concrete Construction and Materials and Commentary
201.2R	Guide to Durable Concrete
221.1R	Report on Alkali-Aggregate Reactivity
223	Standard Practice for the Use of Shrinkage-Compensating Concrete
224R	Control of Cracking in Concrete Structures
229R	Controlled Low-Strength Materials
302.1R	Guide for Concrete Floor and Slab Construction
305R	Hot Weather Concreting
306R	Cold Weather Concreting
308R	Guide to Curing Concrete
309R	Guide for Consolidation of Concrete
318	Building Code Requirements for Structural Concrete
332	Requirements for Residential Concrete Construction and Commentary
347	Guide to Formwork for Concrete
360	Design of Slabs-on-Ground
544.1R	Report on Fiber Reinforced Concrete
546R	Concrete Repair Guide

ASTM International

A 416	Specification for Steel Strand, Uncoated Seven-Wire for Prestressed Concrete
A 615	Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement
A 820	Specification for Steel Fibers for Fiber-Reinforced Concrete

C 31	Practice for Making and Curing Concrete Test Specimens in the Field
C 33	Specification for Concrete Aggregates
C 39	Test Method for Compressive Strength of Cylindrical Concrete Specimens
C 94	Specification for Ready-Mixed Concrete
C 143	Test Method for Slump of Hydraulic Cement Concrete
C 150	Specification for Portland Cement
C 260	Specification for Air-Entraining Admixtures for Concrete
C 295	Guide for Petrographic Examination of Aggregates for Concrete
C 311	Test Methods for Sampling and Testing Fly Ash or Natural Pozzolans for Use in Portland-Cement Concrete
C 330	Specification for Lightweight Aggregates for Structural Concrete
C 403	Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance
C 441	Test Method for Effectiveness of Pozzolans or Ground Blast-Furnace Slag in Preventing Excessive Expansion of Concrete Due to the Alkali-Silica Reaction
C 494	Specification for Chemical Admixtures for Concrete
C 595	Specification for Blended Hydraulic Cements
C 618	Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete
C 685	Specification for Concrete Made by Volumetric Batching and Continuous Mixing
C 979	Specification for Pigments for Integrally Colored Concrete
C 989	Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars
C 995	Test Method for Time of Flow of Fiber-Reinforced Concrete Through Inverted Slump Cone
C 1017	Specification for Chemical Admixtures for Use in Producing Flowing Concrete
C 1116	Specification for Fiber-Reinforced Concrete and Shotcrete
C 1157	Performance Specification for Hydraulic Cement
C 1240	Specification for Silica Fume Used in Cementitious Mixtures
C 1260	Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method)
C 1293	Test Method for Determination of Length Change of Concrete Due to Alkali-Silica Reaction
C 1299	Guide for Use in Selection of Liquid-Applied Sealants
C 1567	Test Method for Determining the Potential Alkali-Silica Reactivity of Combinations of Cementitious Materials and Aggregate (Accelerated Mortar-Bar Method)
C 1602	Specification for Mixing Water Used in the Production of Hydraulic Cement Concrete
C 1611	Test Method for Slump Flow of Self-Consolidating Concrete
D 2487	Classification of Soils for Engineering Purposes (Unified Soil Classification System)

International Code Council

IRC	International Residential Code for One- and Two-Family Dwellings

National Ready Mixed Concrete Association

CIP 2	Scaling Concrete Surfaces
CIP 3	Crazing Concrete Surfaces
CIP 4	Cracking Concrete Surfaces
CIP 5	Plastic Shrinkage Cracking
CIP 6	Joints in Concrete Slabs on Ground
CIP 8	Discrepancies in Yield
CIP 11	Curing In-Place Concrete
CIP 12	Hot Weather Concreting
CIP 13	Concrete Blisters
CIP 14	Finishing Concrete Flatwork
CIP 15	Chemical Admixtures for Concrete
CIP 16	Flexural Strength of Concrete
CIP 23	Discoloration
CIP 24	Synthetic Fibers for Concrete
CIP 27	Cold Weather Concreting
CIP 28	Concrete Slab Moisture
CIP 29	Vapor Retarders Under Slabs on Ground
CIP 30	Supplementary Cementitious Materials
CIP 31	Ordering Ready Mixed Concrete
CIP 35	Testing Compressive Strength of Concrete
CIP 37	Self Consolidating Concrete

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www.astm.org

International Code Council
5203 Leesburg Pike, Suite 600
Falls Church, VA 22041-3401
www.iccsafe.org

National Ready Mixed Concrete Association
900 Spring St.
Silver Spring, MD 20910
www.nrmca.org

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