

ACI 332.1R-18

Guide to Residential Concrete Construction

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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 residential concrete that meets or exceeds code requirements. It covers concrete work for one- and two-family dwellings with a maximum height of three stories above grade and a basement that is either cast-in-place or placed as precast members. 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 above-grade concrete systems (Chapter 6) and project considerations (Chapter 8) are included. Common problems and their repair are also addressed. Although the discussion of specific design provisions and all drawings provided by this guide are intended to offer illustrations of typical practice, they should be verified as to whether they meet 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; foundation; form; residential; slab; slab-on-ground; subgrade; tolerance; wall.

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CONTENTS

CHAPTER 1—INTRODUCTION, p. 2

1.1—Scope, p. 2

CHAPTER 2—DEFINITIONS, p. 2

CHAPTER 3—CONCRETE, p. 3

3.1—Fundamentals, p. 3

3.2—Materials, p. 3

3.3—Concrete properties, p. 5

3.4—Mixture proportioning, p. 8

3.5—Ordering, p. 10

3.6—Production and delivery, p. 10

3.7—Testing, p. 11

CHAPTER 4—FOOTINGS, p. 11

4.1—Purpose, p. 11

4.2—Footing types, p. 11

4.3—Footing design considerations, p. 12

4.4—Footing construction, p. 19

4.5—Tolerances, p. 21

CHAPTER 5—BELOW-GRADE WALLS, p. 22

5.1—Forming systems for cast-in-place walls, p. 22

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- 5.2—Precast systems, p. 24
- 5.3—Geometry, p. 25
- 5.4—Reinforcement, p. 26
- 5.5—Wall construction, p. 29
- 5.6—Curing and protection, p. 34
- 5.7—Moisture protection, p. 35
- 5.8—Backfilling, p. 36
- 5.9—Safety, p. 37

CHAPTER 6—ABOVE-GRADE CONCRETE SYSTEMS, p. 38

- 6.1—Overview, p. 38
- 6.2—Above-grade walls, p. 39
- 6.3—Materials and placement, p. 41
- 6.4—Insulation systems, p. 42
- 6.5—Design considerations, p. 43
- 6.6—Exposed wall finishes, p. 44
- 6.7—Services, p. 44

CHAPTER 7—SLABS, p. 46

- 7.1—Slabs-on-ground, p. 46
- 7.2—Elevated slabs, p. 48
- 7.3—Concrete, p. 49
- 7.4—Placing and finishing, p. 49
- 7.5—Jointing, p. 52
- 7.6—Curing, p. 53
- 7.7—Exposed floor finishes, p. 54

CHAPTER 8—PROJECT CONSIDERATIONS, p. 54

- 8.1—Ordering ready mixed concrete, p. 54
- 8.2—Site considerations, p. 54
- 8.3—Placement considerations, p. 55
- 8.4—Special materials, p. 56
- 8.5—Hot weather concreting, p. 56
- 8.6—Cold weather concreting, p. 57
- 8.7—Troubleshooting, p. 57

CHAPTER 9—REFERENCES, p. 60

Authored documents, p. 61

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 (PCA MI451D).

1.1—Scope

This guide provides practical information about the construction of residential concrete that meets or exceeds code requirements, covering all concrete work within the scope defined in the “International Residential Code for One- and Two-Family Dwellings” (International Code Council 2018) and that of ACI 332. Provisions of these codes apply to detached one- and two-family dwellings and multiple single-family dwellings (townhomes) not more than three stories in

height. These structures are no more than three stories above grade and may include a basement that is either cast-in-place or placed as precast members. 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 above-grade concrete systems in Chapter 6 and project considerations in Chapter 8 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 excluded from this guide includes deep foundation systems (such as piles, drilled piers, or caissons), free-standing retaining walls (greater than 4 ft [1.2 m]), and post-tensioned slabs-on-ground. Limited information on the use of lightweight concrete is presented. This guide 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 for One- and Two-Family Dwellings” (International Code Council 2018).

CHAPTER 2—DEFINITIONS

Please refer to the latest version of ACI Concrete Terminology for a comprehensive list of definitions. Definitions provided herein complement that resource.

anchor strap—metal connector with corrosion resistance designed to transfer uplift, lateral forces, or both, from wood framing members to concrete foundations.

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

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.

flowable fill—self-consolidating cementitious material used primarily as a backfill in place of compacted fill.

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

hydrostatic pressure—pressure on a foundation wall due to water.

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

moderately reinforced walls—structural concrete walls reinforced with an amount of steel reinforcement greater than that of a minimum reinforcing bar and welded wire reinforcement less than that

required by **ACI 332** or **ACI 318** and shown to satisfy the design requirements for applied load without the need for additional steel reinforcement including reinforcing bar and welded wire reinforcement.

pad footing—isolated footing or column support that transfers vertical load from the structure above to the soil.

plain reinforced walls—structural concrete walls with no reinforcement required for design forces or with steel reinforcement including reinforcing bar and welded wire reinforcement for temperature, shrinkage, and crack control only.

reinforced walls—structural concrete walls reinforced with no less than the minimum amount of steel reinforcement including reinforcing bar and welded wire reinforcement required by **ACI 332**.

removable concrete form—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.

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.

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

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

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

viscosity-modifying admixture—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 self-consolidating concrete mixtures.

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

CHAPTER 3—CONCRETE

3.1—Fundamentals

The main constituents for concrete used in residential construction include cementitious materials (portland cement and supplementary cementitious materials [SCMs]), coarse aggregate (stone or gravel), fine aggregate (sand), and water. Concrete mixtures have become much more complex in the range of additional components, as designers and contractors have been introduced to the benefits of performance-enhancing ingredients. These include a variety of chemical admixtures, fibers, and mineral pigments for such applications as decorative concrete. The ready mixed concrete producer can vary the proportions of ingredients to create a concrete mixture with specific properties to meet specific building code requirements, respond to specific or

anticipated environmental conditions, and meet the purchaser's or contractor's requirements. The performance of the concrete should meet the requirements of **ACI 332**, **ASTM C94/C94M**, or **C685/C685M**; other applicable building code requirements; and the project specifications.

3.2—Materials

3.2.1 Cementitious materials—Cementitious materials include portland cement, blended cements, and supplementary cementitious materials (SCMs). A cementitious paste is formed by the combination of cementitious materials and water, and serves several functions: to coat and bond the aggregate particles together; to fill the void spaces between the aggregate; and to provide strength and durability to the hardened concrete. For any combination of materials, the strength of the resulting concrete mixture depends primarily on the water-cementitious materials ratio (w/cm). Increasing the amount of cementitious materials in relation to the amount of water in the mixture will generally increase the compressive strength. Using less water for a fixed amount of cementitious material results in a more viscous paste and stronger concrete. The amount of shrinkage in the hardened concrete is directly proportional to the amount of water in the mixture. Most cementitious materials for residential construction generally consist of a combination of portland cement and SCMs in the form of fly ash, slag, or both.

3.2.2 Portland cement—Portland cement is the most common type of cement used in concrete. **ASTM C150/C150M** defines five types of portland cement, but only four are typically used in residential construction. Type I is a general-purpose cement and is the most commonly used cement for residential concrete; Type II is a cement used where moderate sulfate exposure is anticipated; 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.

3.2.3 Blended cements and hydraulic cement—Blended cement, defined by **ASTM C595/C595M**, consists of preblended combinations of portland cement and SCMs. Hydraulic cements may or may not contain portland cement and are defined by **ASTM C1157/C1157M**. Both cement types are used in residential construction.

3.2.4 Supplementary cementitious materials—Natural pozzolans (**ASTM C618** Class N), fly ashes (**ASTM C618** Class C or F), and slag cements (**ASTM C989/C989M** Grades 80, 100, and 120), are some of the materials known as SCMs that are used in residential concrete. The benefits derived from the use of SCMs include functional or engineering benefits and environmental benefits. Some of the engineering benefits are decreased permeability, increased durability, improved workability, and higher ultimate compressive strength. The environmental benefits are reduced consumption of portland cement, which results in a lower carbon footprint for the concrete and a reduction in the amount of industrial by-products that are diverted to landfills. **NRMCA CIP 30** provides further information on SCMs and **PCA EB001**.

3.2.5 Aggregates—Aggregates are the major constituent in concrete, typically comprising 70 percent or more of the volume. They are an economical material that imparts volume stability, strength, and durability to concrete. Aggregates have significant influence on the properties and performance of both plastic (freshly mixed) and hardened concrete, depending on mineralogy and physical characteristics. Aggregates used in concrete include coarse aggregate (gravel or crushed stone) and fine aggregate (natural sand or crushed stone). Other materials used for aggregate in concrete include lightweight processed shale or slate, air-cooled blast furnace slag, and other natural and manufactured materials.

3.2.5.1 Coarse aggregate (gravel or crushed stone)—Aggregate particles that are cubical or rounded facilitate better workability of the concrete, but higher compressive strength and bond comes from angularity and roughness. However, aggregate shape is often determined by the locally available sources. The aggregates should be clean and graded, with particle sizes ranging from 1/4 in. (5 mm) to 3/4 or 1 in. (19 or 25 mm) for most residential concrete. The applicable standard for coarse aggregates is [ASTM C33/C33M](#).

3.2.5.2 Fine aggregate (sand)—ASTM C33/C33M sets limits for fine aggregates on impurities (organic materials, clay, and others) and soundness, as well as establishing gradation requirements. Fine aggregate particles range in size between 0.0118 in. (300 μ m) and 1/4 in. (5 mm).

3.2.6 Water—The applicable standard for water used in mixing concrete is [ASTM C1602/C1602M](#). Potable water from municipal or well sources is commonly used for batching concrete. Recycled water meeting ASTM C1602/C1602M can also be used. The suitability of any water is established by testing concrete or mortar for setting time and compressive strength relative to a control, with optional chemical limits for chlorides, sulfates, alkalis, and total dissolved solids.

3.2.7 Chemical admixtures—A variety of chemical admixtures are used to modify the placing and finishing characteristics of the concrete. The contractor and concrete producer should discuss the benefits of chemical admixtures and when their use is planned by the concrete producer. More information about chemical admixtures can be found in [NRMCA CIP 15](#) and [PCA EB001](#).

3.2.7.1 Air-entraining agents—Air-entraining agents may be used to provide air entrainment in concrete, which is an effective method for imparting freezing-and-thawing resistance to concrete (refer to 3.3.2.3 for more discussion on air entrainment). The applicable standard for air-entraining agents is [ASTM C260/C260M](#).

3.2.7.2 Water reducers—Normal water reducers lower the amount of water required to achieve a given slump. The applicable standard for normal water reducers is [ASTM C494/C494M](#) Type A.

3.2.7.3 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 C494/C494M Type D.

3.2.7.4 Mid-range water reducers—Mid-range water-reducing admixtures provide moderate water reduction without retardation associated with high dosages of conventional (normal) water reducers. These admixtures provide more water reduction than normal water reducers (5 percent), but less water reduction than high-range water-reducing admixtures (HRWRAs) (12 percent). This typically results in concrete with a slump range of 5 to 8 in. (125 to 200 mm). Mid-ranges will commonly meet ASTM C494/C494M Types A and F. These admixtures are commonly used in residential concrete.

3.2.7.5 High-range water-reducing admixtures—HRWRAs produce higher water reductions than normal water reducers. The applicable standard for HRWRAs is ASTM C494/C494M Type F (for normal setting) or Type G (for retarded set).

3.2.7.6 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 C1017/C1017M](#) Type I (plasticizing) and Type II (plasticizing and retarding).

3.2.7.7 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 SCMs to produce self-consolidating concrete (SCC) mixtures. More information on SCC can be found in [NRMCA CIP 37](#) and [PCA EB001](#).

3.2.7.8 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 C494/C494M Type E.

3.2.7.9 Accelerators—Calcium chloride is an effective and commonly used accelerator in residential concrete. The amount used should not exceed 2 percent by weight of cementitious materials, where reinforced concrete is dry and protected from moisture in service conditions, or for plain (unreinforced) concrete in all service conditions. For reinforced concrete subject to other service condition, calcium chloride should not exceed 0.50 percent by weight of cementitious materials. Maximum allowable limits for the use of calcium chloride for residential applications are provided in Table 5.3.2 of [ACI 332-14](#). 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 reinforced concrete that is wet in service. These nonchloride accelerators are effective for set acceleration and compressive strength development. The applicable standard for accelerating admixtures is ASTM C494/C494M Type C.

Table 3.2.8.1—Fibers: Properties and use

	Microfibers		Macrofibers
Fiber configuration	Monofilament	Fibrillated	Monofilament/fibrillated
Function	Plastic shrinkage only Settlement/relaxation lessened	Plastic shrinkage Settlement/relaxation lessened	Plastic shrinkage (not applicable for steel fibers) Settlement/relaxation lessened Temperature and shrinkage crack control
Benefits	Precrack	Precrack	Precrack Post-crack
Fiber materials	Dosage*	Dosage*	Dosage*
Synthetics	0.5 to 1.0 lb/yd ³ (0.3 to 0.6 kg/m ³)	1.5 to 3.0 lb/yd ³ (0.9 to 1.8 kg/m ³)	3.0 to 20.0 lb/yd ³ (1.8 to 11.9 kg/m ³)
Natural	0.5 to 1.0 lb/yd ³ (0.3 to 0.6 kg/m ³)	—	—
Glass	0.5 to 1.0 lb/yd ³ (0.3 to 0.6 kg/m ³)	3.0 to 6.0 lb/yd ³ (1.8 to 3.6 kg/m ³)	6.0 to 30.0 lb/yd ³ (3.6 to 17.8 kg/m ³)
Steel	—	—	15 to 100 lb/yd ³ (8.9 to 59.3 kg/m ³)

*Dosages are for general guidance only. Consult manufacturers' recommendations.

3.2.7.10 Shrinkage reducing admixtures—Although not often used in residential construction, shrinkage-reducing admixtures (SRAs) can be used to reduce drying shrinkage that mainly results from surface tension developed in the small pores of the cement paste of concrete. The SRA reduces shrinkage by reducing the surface tension of water in the pores. Normal dosage rates range from 0.5 to 1.5 gal./yd³ (2.5 to 7.4 L/m³). The applicable standard for SRAs is ASTM C494/C494M Type S. For more information, refer to [ACI 360R](#).

3.2.8 Fibers

3.2.8.1 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 slab-on-ground construction. Table 3.2.8.1 provides a description of fiber properties and use. Further information on synthetic fibers can be found in [ACI 544.1R](#), [ASTM C1116/C1116M](#), [NRMCA CIP 24](#), and [PCA EB001](#).

3.2.8.2 Steel fibers—Steel fibers are seeing increased usage in slabs-on-ground. Table 3.2.8.1 provides a description of fiber properties and use. 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 A820/A820M](#).

3.2.9 Mineral pigments—Mineral pigments meeting [ASTM C979/C979M](#) requirements can be added to color the concrete.

3.3—Concrete properties

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 applicable building code and the design requirements for the specific application. The “International Residential Code for One- and Two-Family Dwellings” ([International Code Council 2018](#)) provides minimum requirements for concrete and references [ACI 332](#), which can provide guidance for if the code is adopted by the local building authority. Additional characteristics are developed based on the intended use of the

concrete, the method of placement and the anticipated conditions at the time of placement, as well as the environmental factors that can affect concrete. The combination of materials used in concrete can affect these plastic concrete properties (concrete before it hardens) and the hardened concrete properties. Concrete producers vary the combination of materials in attempt to meet the requirements of the building code and purchaser (often the building owner [to improve hardened concrete properties]), and the requirements of the contractor (to improve plastic concrete properties).

3.3.1 Plastic concrete properties—Characteristics of plastic concrete are important to those who place and finish concrete. Properly proportioned concrete should be workable and consistent during placement and finishing. Workability and consistency are measured using a property called slump or slump flow. Additional characteristics that impact finishing are setting time and bleeding. Early strength gain can affect the ability to strip formwork and resist freezing and thawing while concrete is hardening.

3.3.1.1 Slump—One measure of concrete consistency or workability (flowability) is called slump. A slump test ([ASTM C143/C143M](#)) measures the consistency of the concrete for slumps up to 9 in. (200 mm), and a modified slump-flow test ([ASTM C1611/C1611M](#)) for self-consolidating concrete (SCC) measures a mixture with greater fluidity. The slump test is performed by filling a truncated cone (Fig. 3.3.1.1a) with concrete and measuring how much the concrete subsides, or slumps, when the cone is lifted. Residential concrete is generally placed with a slump of 4 to 6 in. (100 to 150 mm). A higher slump of 6 to 9 in. (150 to 200 mm) (Fig. 3.3.1.1b) indicates that the concrete is more workable than a lower slump of 1 to 3 in. (25 to 75 mm) (Fig. 3.3.1.1c). Lower-slump concrete is stiffer and more difficult to place into formwork, consolidate, and finish. High slumps, if achieved by only adding water, will result in lower compressive strengths, greater shrinkage characteristics, and freezing-and-thawing resistance problems if the total amount of water added exceeds the maximum *w/cm* designed for the mixture. ACI 332-14 Table 5.1 has maximum slump requirements for different exposures of concrete.



Fig. 3.3.1.1a—Truncated cone for slump tests.



Fig. 3.3.1.1c—Slump test for consistency of concrete illustrating a low slump.



Fig. 3.3.1.1b—Slump test for consistency of concrete illustrating a high slump.



Fig. 3.3.1.2—Modified slump test for measuring flowability of SCC.

3.3.1.2 Slump flow—The slump-flow test (**ASTM C1611/C1611M**) is a procedure used to determine the fluidity or filling ability characteristics of SCC in the absence of obstructions (Fig. 3.3.1.2) 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 slump-flow test is a better indicator to determine the workability for SCC than the usual slump cone procedure (**ASTM C143/C143M**). Within the ASTM C1611/C1611M test method, there are two procedures: upright mold (Procedure A) and inverted mold (Procedure B). The inverted mold makes testing the slump flow a little easier because the cone experiences less uplift as it is filled.

3.3.1.3 Setting time and early strength gain—The 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 C403/C403M**, may range from 4 to 8 hours, depending on cement properties and type, mixture proportions, ambient temperature, and

concrete temperature. If the temperature of plastic concrete is reduced from 70 to 55°F (21 to 13°C), the setting time can increase to approximately 10 hours. Conversely, if this mixture is placed at 90°F (32°C), the setting time decreases to approximately 4 hours.

As the concrete temperature drops below 40°F (4°C), the strength gain can slow until the temperature reaches between 14 and 27°F (–10 and –3°C), at which point hydration will cease. The concrete will resume hardening and gaining strength when the concrete temperature climbs again above this range as long as sufficient moisture for hydration is present. Concrete that reaches a freezing temperature before reaching a compressive strength of 500 psi (3.5 MPa) may be permanently damaged and can suffer significant ultimate strength reduction, although exposure to a single freezing cycle prior to attaining 500 psi (3.5 MPa) may not cause damage. After reaching 500 psi (3.5 MPa), however, concrete will likely reach its potential strength without adverse effects despite subsequent exposure to cold weather. Planning for these severe cold conditions to protect the concrete from freezing until this strength is attained may include a combi-

nation of modifications to the mixture proportions, placement temperatures and practices, insulating products, and supplemental heat, depending on the anticipated minimum temperatures ([ACI 306R](#)).

3.3.1.4 Bleeding—Water that rises to the surface after concrete is placed and before initial set, while the solid materials settle, 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 layer under the finished surface. This can cause surface defects such as crazing, dusting, or scaling in concrete slabs. Finishing operations should not be conducted while bleed water is present.

3.3.1.5 Plastic shrinkage—Plastic shrinkage cracks can sometimes appear on the surface of plastic concrete soon after it is placed. These cracks appear mostly on horizontal surfaces and usually occur at spaces of 1 to 3 ft (300 to 900 mm) apart. Plastic shrinkage cracking occurs when high evaporation rates cause the concrete surface to dry out before it sets. Special precautions need to be taken during ambient conditions of rapid evaporation. Evaporation retardants, which retard moisture evaporation from a fresh concrete surface, may be an aid during these conditions. [NRMCA CIP 5](#) and [PCA IS144](#) provide recommendations for reducing the possibility of shrinkage cracks. Synthetic fibers (macro and micro) have been used in slabs-on-ground to control plastic shrinkage cracking (refer to Table 3.2.8.1 for fiber properties and use).

3.3.2 Hardened concrete properties—Compressive strength, volume stability, and durability are all parameters that affect the performance of hardened concrete. The building owner, through contract documents prepared by licensed design professionals, specifies the hardened concrete properties in construction documents such as construction drawings and specifications. The hardened concrete properties should meet both the minimum requirements of the building code and any additional requirements specified by the purchaser. In some cases, where there are no construction documents, the contractor orders concrete with specific hardened concrete properties in addition to plastic concrete properties.

3.3.2.1 Compressive strength—The compressive strength of concrete at 28 days is typically specified in the design documents or when ordering concrete. Concrete producers can provide a report that will document the strength characteristics of the supplied mixture from previous testing. If required in the project specifications or specified by the purchaser, the compressive strength may be verified by having an ACI Certified Field Testing Technician—Grade I, or equivalent, cast cylinders on the job site in accordance with [ASTM C31/C31M](#) and test them by an accredited laboratory in a compression testing machine in accordance with [ASTM C39/C39M](#). Figure 3.3.2.1 shows a compression test of a cylinder. This strength is expressed in pounds per square inch (psi) or megapascals (MPa). Minimum compressive strength requirements for residential applications are shown in Table 5.3.2 of ACI 332-14. More information on compressive strength of concrete can be found in [NRMCA CIP 35](#) and [PCA EB001](#).



Fig. 3.3.2.1—A concrete cylinder in a test rig is loaded vertically until failure. (Photo courtesy of Portland Cement Association.)

3.3.2.2 Drying shrinkage—Concrete shrinkage is a characteristic of concrete when it dries. Much of the shrinkage takes place at an early age when the concrete is weakest. After 1 year, normal drying shrinkage for concrete is approximately 3/4 in. per 100 ft (19 mm per 30 m). Drying shrinkage is an inherent property of concrete, and shrinkage cracks occur when concrete is restrained. Sources of restraint are the interconnected parts of a structure such as beams, columns, walls, and floors or other building members; the friction of the subgrade on which it is placed; and other obstructions. Cracks will result whenever the tensile stresses exceed the tensile strength. As concrete cools and contracts, tensile stresses develop and could result in cracks, particularly at early ages.

Using concrete joints is the most effective method of controlling cracking. Concrete that is properly divided into smaller sections by control joints to accommodate drying shrinkage and temperature contraction will help initiate cracks to occur at the joints rather than a more random pattern. Control joints are grooved, formed, or sawed into the concrete to provide predetermined weakened locations for the concrete to crack due to the stress developed during normal shrinkage. Figure 3.3.2.2 shows a control 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. More information on joints in concrete slabs-on-ground can be found in [NRMCA CIP 6](#), [PCA IS144](#), and [PCA EB122](#).



Documents

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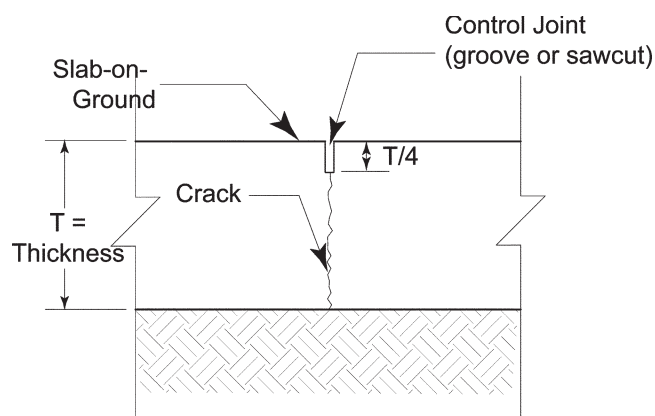


Fig. 3.3.2.2—Joint for crack control.

Other methods for controlling shrinkage cracking include proper mixture design, shrinkage-reducing admixtures, macrofibers, proper finishing and curing, and steel reinforcement such as reinforcing bar and welded wire reinforcement.

In general, limit slump to less than 5 in. (125 mm) when water-reducing admixtures are not used and avoid retempering concrete to increase slump prior to placement. Higher slump (up to 6 to 7 in. [150 to 175 mm]) can be used provided the mixture is designed to produce the required strength without excessive bleeding, segregation, or both. This is generally accomplished by using water-reducing admixtures. Using larger aggregates and reducing cementitious materials tends to reduce drying shrinkage.

Curing is an important step to minimize drying shrinkage, especially during the first 3 days. Start curing as soon as possible following suggestions given in 4.4.5, 4.4.5.2, 5.6, 5.6.3, 7.6, 7.6.1, and 7.6.3.

Steel reinforcement, some fibers, or both, can help control drying shrinkage cracking. As concrete shrinks and cracks, tension is imparted to the steel reinforcement or fibers (3.2.8), which helps reduce the width of cracks. It is important to place shrinkage and temperature reinforcement within the middle one-third of a slab or wall such that there is sufficient cover (at least 2 in. [50 mm]) for exterior concrete, thus minimizing the amount of salt and moisture that can reach the steel and cause corrosion. Shrinkage-reducing admixtures can also be used to minimize drying shrinkage (3.2.7.10).

3.3.2.3 Air entrainment—The use of entrained air in a concrete mixture affects both the plastic and hardened characteristics. A chemical admixture is added to the concrete to produce microscopic, closely spaced air bubbles, which improves the workability and may reduce the amount of water required for a given consistency. The addition of entrained air may reduce the water demand and the amount of bleed water. Once concrete hardens, these bubbles remain as discreet voids. This air-void system primarily acts as a pressure-relief mechanism that can protect the concrete from the effect of water expanding as it freezes. Any concrete that will be wet in service and subjected to freezing and thawing should contain entrained air for improved durability. Generally, the amount of entrained air by volume is between 4.5

and 7.5 percent, depending on the exposure and maximum aggregate size.

3.4—Mixture proportioning

To establish concrete mixture proportions, concrete producers consider specified compressive strength (f'_c); durability; workability; placing and finishing; drying shrinkage; economy; aesthetics; and other properties specified by purchaser, licensed design professional, and contractor. ACI 332 provides minimum requirements for concrete strength and durability, depending on the application such as foundations, walls, or slabs and their exposure to freezing and thawing, sulfates in soils, or water in contact with concrete or the potential for corrosion of reinforcement. ACI 332 requires that the value of f'_c be the greatest of the values needed for compressive strength to meet design requirements or as required for durability. The concrete producer proportions concrete mixtures to achieve an average strength higher than the specified compressive strength and other requirements in Chapter 5 of ACI 332-14. Table 5.2.1 of ACI 332-14 defines exposure categories and classes. Table 5.3.2 of ACI 332-14 defines the requirements for concrete, depending on exposure class assigned to the concrete member. Table 5.4.1 of ACI 332-14 provides minimum air content requirement for concrete exposed to freezing and thawing. Table 5.4.2 of ACI 332-14 provides limits on supplementary cementitious materials (SCMs) for concrete exposed to very severe freezing and thawing. Table 5.5.1 of ACI 332-14 provides requirements for establishing suitability of cementitious materials combinations exposed to water-soluble sulfates. The user of ACI 332 is encouraged to develop a table to assign exposure classes for each concrete member on a residential project as shown in Table 3.4.

3.4.1 Exposure categories and classes—ACI 332 indicates that exposure classes will be assigned to concrete members based on the severity of the anticipated exposure for each category according to Table 5.2.1 of ACI 332-14 or as determined by the local building official.

3.4.1.1 Exposure Category RF (freezing and thawing)—Concrete can potentially deteriorate when exposed to freezing-and-thawing cycles when any portion of the member is in a critically saturated condition during freezing weather. Exposure Category RF defines four classes of exposure for freezing and thawing. Exposure Class RF0 should be assigned to interior concrete and to footings, foundations, and basement walls submerged in the ground. Basement and foundation walls that extend above grade less than 12 in. (300 mm) are unlikely to be saturated and could generally be assigned Exposure Class RF0. Exposure Class RF1 should be assigned to vertical concrete members where excessive accumulation of ice and snow is not anticipated. Examples include above-grade foundation walls, such as stem walls, walk-out basement walls, and columns. Exposure Class RF2 should be assigned to elevated or on-grade horizontal concrete members that have a likelihood of prolonged contact with water to achieve a saturation state. Examples include concrete roofs, patios, or other slabs. If it is anticipated that deicing chemicals will not be used, Exposure

Table 3.4—Exposure classes to be assigned for concrete members

Concrete member*	Exposure class†		
	RF: freezing and thawing	RS: sulfate	RC: corrosion protection of reinforcement
Footings, foundation walls, and basement walls not exposed to weather	RF#	RS#	RC#
Basement slabs and interior slabs-on-grade	RF#	RS#	RC#
Footings, foundation walls, basement walls, and exterior walls exposed to weather	RF#	RS#	RC#
Driveways, curbs, walks, patios, porches, steps and stairs, and unheated garage floors exposed to weather	RF#	RS#	RC#

*Depending on the project and or exposure conditions, fewer or additional concrete members may need to be defined for purposes of assigning exposure classes.

†For each concrete member, the corresponding exposure classifications should be placed in the appropriate cell and compared to determine the most restrictive requirements for concrete per 6.3.1 # is 0, 1, 2, etc. based on the severity of exposure selected in 3.4.1.

Class RF3 should be assigned to the same type of members as in RF2 but where the application of deicing chemicals is anticipated. Examples include driveways, curbs, steps, stairs, and porches.

3.4.1.2 Exposure Category RS (sulfate exposure)—Concrete can potentially deteriorate when exposed to sulfates in soil or water. Exposure Category RS should be based on a measurement or knowledge of the concentration of soluble sulfates in soil or water that will be in contact with the relevant concrete member. The standards referenced in ACI 332 should be used to measure the sulfate concentrations. Other methods can provide different results compared to the methods referenced. Where the predominant soil sulfates are in the form of gypsum, the measured sulfate content will be higher and these criteria will be conservative. For these cases, it is preferred that a test with a history of successful use in the geographic area of the project be permitted and approved by the local building official. There are four classes of sulfate exposure, ranging from RS0 (not applicable) to RS3 (very severe). Although concentration of soluble sulfates in seawater will be high, members exposed to seawater should be assigned to Exposure Class RS1 because marine concrete does not experience expansive formation of ettringite. More information on sulfate attack of concrete is found in [PCA EB001](#).

3.4.1.3 Exposure Category RC (corrosion protection of reinforcement)—Exposure Category RC is only applicable to concrete members with structural reinforcement and not plain concrete. The corrosion of the small amount of reinforcement used as shrinkage and temperature steel in plain concrete members does not present a problem, whereby the structural safety of the member will be compromised. There are three classes of corrosion protection of reinforcement, ranging from RC0 (not applicable) to RC2 (severe).

3.4.2 Strength—The required compressive strength for residential concrete is largely determined by structural and durability requirements, including concrete exposed to freezing and thawing (Exposure Category RF), concrete in contact with sulfates in the soils or water (Exposure Category RS), or reinforced concrete where corrosion protection of reinforcement is critical (Exposure Category RC). [ACI 332-14](#) Table 5.2.1 defines the different exposure categories and classes for residential concrete. Tables 5.3.2, 5.4.1, 5.4.2,

and 5.5.1 of ACI 332-14 gives requirements for minimum specified compressive strengths, slump, air content, and limitations on cementitious materials and chlorides in concrete for various types of construction in different exposure categories and classes.

3.4.3 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. Concrete strength and durability generally increase with a reduction in the w/cm . Although the addition of water to a concrete mixture with no other proportion changes will make the concrete more workable, it will also decrease its strength and durability. ACI 332 does not specify limits on w/cm ; however, it does provide requirements for strength and slump, which serve as a surrogate for w/cm .

3.4.4 Freezing-and-thawing resistance—In areas where freezing and thawing occur, the durability of exterior concrete is always a concern. Air entrainment will improve the resistance of concrete exposed to freezing-and-thawing cycles. Air entrainment in concrete improves its 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. ACI 332-14 Table 5.4.1 provides minimum requirement for the proper amount of air entrainment for various coarse aggregate sizes and exposure classes. The need for adequate curing of the concrete cannot be over-emphasized. Curing has a strong influence on the properties of hardened concrete such as durability, strength, permeability, abrasion resistance, volume stability, resistance to freezing and thawing, and resistance to deicer salts.

In general, freezing-and-thawing resistance is most critical for exterior concrete (Table 3.4). The minimum compressive strength of slabs-on-ground depends on the classification of the slab. Classification, strength, and other pertinent information regarding slab-on-ground construction are found in ACI 332-14 Tables 5.2.1 and 5.3.2. Strength and slump requirements are provided in ACI 332-14 Table 5.3.2. In addition to minimum compressive strength and maximum slump, there are also requirements for minimum air content in ACI 332-14 Table 5.4.1 and limitations on supplementary materials in ACI 332-14 Table 5.4.2.



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Deicing chemicals can cause severe durability problems 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 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. Additional information is provided in [PCA EB001](#), [PCA IS177](#), and [ACI CCS-1](#).

3.4.5 Sulfate attack—Concrete that will be exposed to elevated levels of water-soluble sulfates should be proportioned to provide adequate sulfate resistance. [ACI 332](#) provides requirements to control sulfate attack. [ACI 332-14](#) Table 5.3.2 provides mixture requirements for concrete. Alternate requirements are provided in Table 5.5.1 of [ACI 332-14](#).

3.4.6 Corrosion protection of reinforcement—Corrosion of reinforcement is aggravated by chlorides in concrete. For Exposure Classes RC1 and RC2, chloride ion content in concrete is limited in reinforced concrete, as detailed in Table 5.3.2 of [ACI 332-14](#).

3.4.7 Coarse aggregate size—The size of coarse aggregate also affects the workability and the ability for concrete to be properly consolidated in the formwork, thus reducing the ability for concrete to reach its ultimate strength and durability characteristics. [ACI 332](#) indicates that the nominal maximum size of coarse aggregate shall not exceed the smallest of:

- (a) 1/5 of the minimum wall thickness
- (b) 1/3 of the cross-sectional dimension of a member
- (c) 3/4 of the specified minimum clear spacing between reinforcing bars or clear cover

3.4.8 Alkali-silica reactivity—Most aggregates are relatively inert and are not reactive in concrete; however, some aggregates with siliceous components (opaline chert, strained quartz, and acidic volcanic glass) are reactive in combination with cementitious materials containing high alkalis (sodium and potassium). This reaction is called alkali-silica reactivity (ASR) and causes internal stresses with exposure to moisture, such as in exterior concrete. The pressure results in expansion, inducing cracks near the aggregates, which starts the process of concrete deterioration. 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 percent. Because this is difficult to achieve, beneficial actions include the use of a low-alkali cement ([ASTM C150/C150M](#) portland cements), the use of blended cements or supplementary cementitious materials (SCMs), limiting the alkali content of the concrete, and the use of suitable chemical admixtures. [ACI 221.1R](#) cites [ASTM C441/C441M](#) as the test method that evaluates the effectiveness of SCMs in reducing expansions due to ASR. [ASTM C311/C311M](#) provides a procedure

for evaluating the effectiveness of SCMs in reducing ASR expansion that is a modification of [ASTM C441/C441M](#). [ASTM C1260](#) and [C295/C295M](#) can be used to identify and confirm the existence of nonreactive aggregate. [ASTM C1567](#) or [C1293](#) can be used to optimize the amount of SCMs to control ASR. For further information on this subject, refer to [ACI 221.1R](#).

3.5—Ordering

Ready mixed concrete producers supply concrete for the vast majority of residential construction. Some specifications limit the time between the initial addition of water and final placement to 90 minutes. 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 design and the use of admixtures can extend the time allowed for final placement.

When placing an order for concrete, numerous 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 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 mockup section is suggested so that all parties agree to the acceptable color, texture, and overall appearance of the concrete. [NRMCA CIP 31](#) provides guidelines on ordering concrete.

A contractor should order concrete by providing the specified compressive strength and the exposure class for the concrete and any other requirements for the concrete. It is also suggested that the intended use or application for the concrete, placement method, and any other requirements in the construction documents be communicated to the concrete producer. An example is placing an order for concrete for cold weather climates for a basement wall. Placement details would be: basement wall concrete being pumped; $f'_c = 3000$ psi (20 MPa); Exposure Class RF0, FS0, and RC0; slump of 8 in. (200 mm) pumped through a 6 in. (150 mm) pump line; and maximum aggregate size of 3/4 in. (19 mm).

3.6—Production and delivery

Ready mixed concrete producers 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 C94/C94M](#). 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. Continued retempering with water is not recommended. The amount of added water should be documented. If the addition of water exceeds the maximum water permitted in the mixture proportions, it

may have an undesirable effect on the concrete properties, including reduced compressive strength and durability.

3.7—Testing

Although field testing of concrete is not normally performed on residential work unless required in the contract documents or the local building code, to assure mixture performance, proper testing should be conducted by the producer to verify the consistency of the concrete supplied. 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 at regular intervals. The purchaser may request documentation demonstrating that the concrete being supplied will achieve the strength requirements. **ACI 301** provides guidance for proportioning mixtures to meet specified compressive strength. If strength verification is required, cylinders taken by an ACI Certified Field Testing Technician—Grade I or equivalent, during time of placement, should be tested according **ASTM C39/C39M**. The concrete strength is considered satisfactory as long as averages of any three consecutive strength tests remain above the specified f'_c and no individual strength test falls below the specified f'_c by more than 500 psi (3.5 MPa). Proper testing of concrete on larger projects can reduce the cost associated with troubleshooting problems should they occur.

When it is determined that the concrete does not meet the specified compressive strength requirements (or other criteria specified by the purchaser), there are several pathways to achieve a remedy. First, nondestructive field tests can be performed on the concrete to provide qualitative comparisons about strength for any portion of the structure. The most common of these tests are the rebound hammer (**ASTM C805/C805M**) and the pulse-velocity method (**ASTM C597**). Second, concrete cores can be taken from the structure in question and tested in accordance with **ASTM C42/C42M**. This is a more reliable method for testing the compressive strength of in-place concrete, but it does introduce destructive testing or the potential for significant repair. **ACI 214R** and **318** provide guidance on core testing and acceptance. In some cases, if these field tests fail to demonstrate compliance with the purchaser's requirements, then it may be necessary for the contractor to engage an engineer to demonstrate that the structure will perform as intended even if the compressive strength is lower than specified. Although not desirable, in extreme cases, the concrete may need to be removed and replaced. **ACI 318**, **ACI 301**, and **ASTM C94/C94M** provide guidance on these remedy procedures.

CHAPTER 4—FOOTINGS

This chapter provides discussion and guidance for the design and construction of footings for residential structures not more than three stories above grade and a basement. Additional requirements on the use and application of these



Fig. 4.1—The footing projection should be large enough to accommodate the forms.

guidelines may be governed by project specifications, local codes, or soil conditions. Provisions for the design of footings can be found in Chapter 7 of **ACI 332-14**. 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.

4.1—Purpose

There are three primary purposes for footings as described in this section. First, footings function to distribute vertical structural loads to the ground from the structure. Second, footings anchor the foundation wall at the lower end against the lateral pressures of the retained soils. Third, footings serve an important function during construction, as they establish tolerance controls by providing a level and consistent support for setting the wall forming system, as shown in Fig. 4.1.

4.2—Footing types

Footing types fall into three classifications: continuous footings, pad footings, and thickened slabs.

4.2.1 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 footing should be centered under the foundation wall (Fig. 4.2.1a) so as not to eccentrically load the footing, unless expressly designed by the licensed design professional. Continuous footings may be reinforced with steel as shown in Fig. 4.2.1b.

4.2.2 Pad footing—A pad footing (Fig. 4.2.2), also known as a spread footing, is typically used to transfer concentrated loads such as from columns or piers, 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.

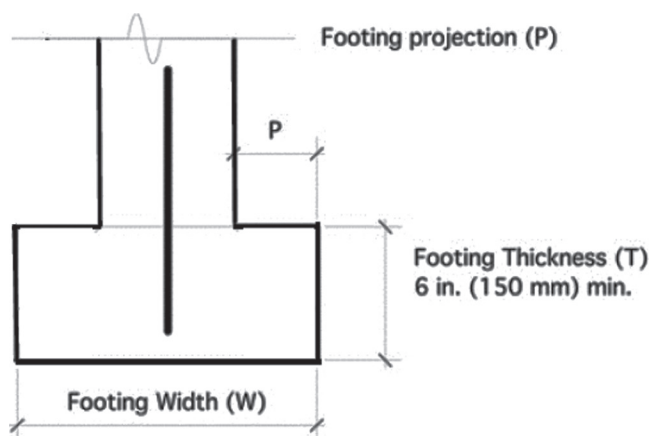


Fig. 4.2.1a—Unreinforced footing.



Fig. 4.2.1b—Reinforced footing.

4.2.3 Thickened slab—In regions where frost depth is shallow or where a frost-protected shallow foundation is designed, the edges of the concrete slab may be thickened to create a continuous footing. Similarly, these thickened regions may be required at designed locations within the field of the slab to support a bearing wall (continuous) or a bearing post (pier). These conditions are referred to as thickened slabs because they are often placed integrally or monolithically with the floor slab (Fig. 4.2.3). This is also sometimes referred to as a shovel footing because they are dug out by hand below the finished slab elevation after the primary excavation has been completed.

4.3—Footing design considerations

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

4.3.1.1 Vertical loads—Vertical loads (gravity loads) are classified in two broad categories: dead loads and live loads. Dead loads typically include the weight of the structure before the owner moves in, including footings and foundation walls, floor and roof material loads, and any other nonmoveable or

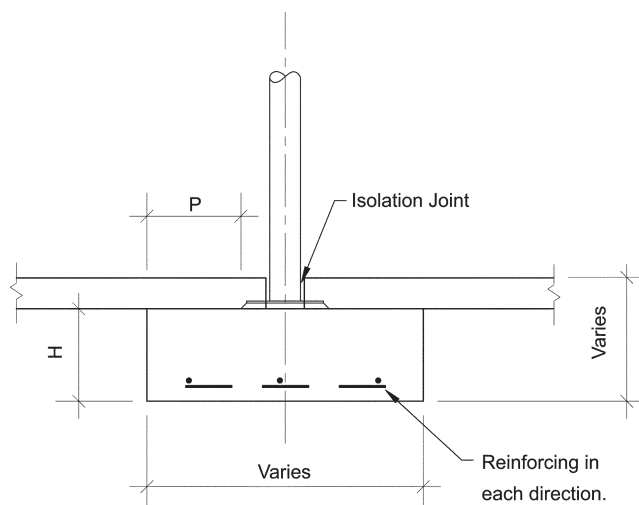


Fig. 4.2.2—Pad footing.

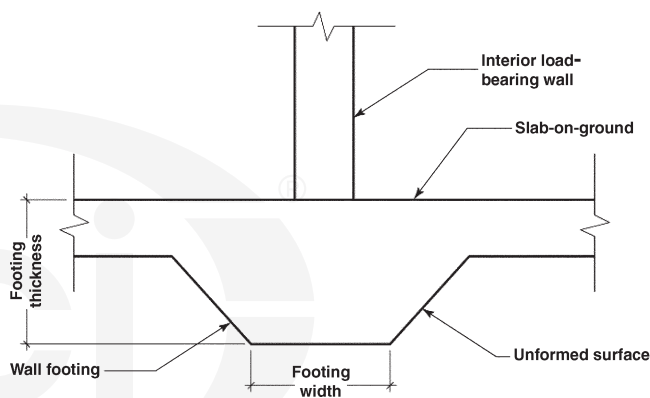


Fig. 4.2.3—Thickened slab.

permanent component. Live loads, then, are any applied loads to the structure. These include transient loads that the owners bring in with them when they move in, such as occupants, furniture, and housewares that are not permanently attached to the structure. The minimum uniformly distributed live load design requirements can typically be obtained from the “International Residential Code for One- and Two-Family Dwellings” ([International Code Council 2018](#)), [ACI 332](#), or the applicable model building codes and are shown in Fig. 4.3.1.1. Other vertical loads might include snow load, uplift load from wind, and impact loads.

Vertical loads from the foundation walls are transferred through the footings to the ground. In basic terms, knowing the vertical load and the soil-bearing pressure from the ground, the footing size can be calculated as shown in 4.3.1.3.

4.3.1.2 Lateral loads—Lateral loads are horizontal forces applied in a direction perpendicular or parallel to the plane of the vertical wall and consist primarily of wind, seismic, soil, and hydrostatic soil pressure loads. They could also include excessive live loading from vehicles or storage adjacent to a wall, depending on the distance of the surcharge. The primarily perpendicular forces to the plane of the vertical wall create bending moments in the wall due to the supported end conditions at the floor framing and footing connection.

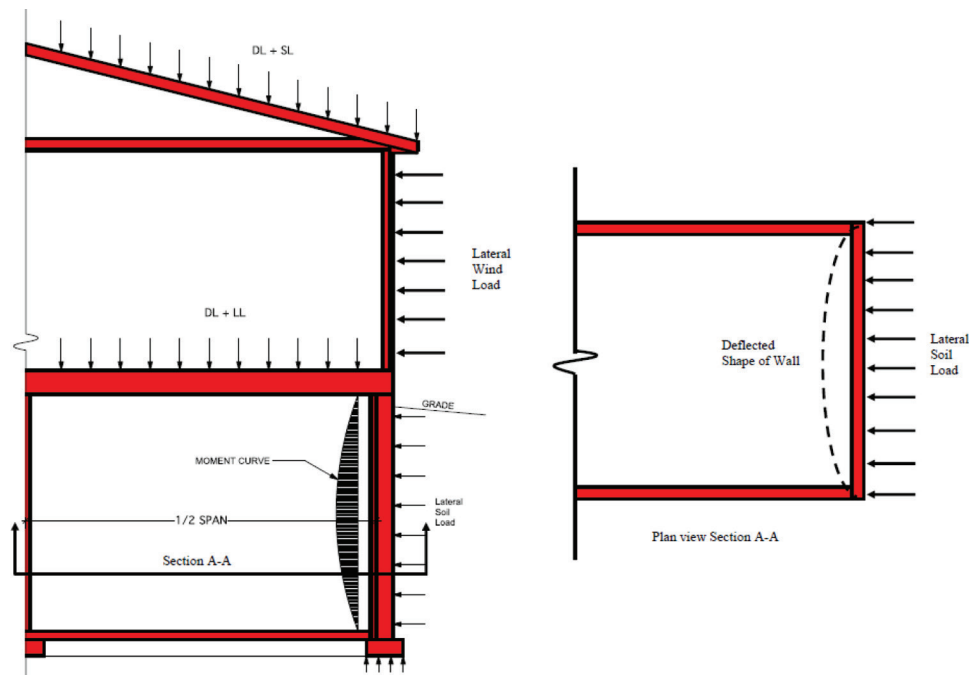


Fig. 4.3.1.1—Load diagram.

as shown in Fig. 4.3.1.1. The perpendicular force is applied from the direction the wind originates while the parallel force is created by the transfer of the perpendicular force into the adjacent side walls. Soil pressures produce loads perpendicular to the plane of the wall.

Lateral loads on walls supported by footings result in horizontal forces on the footings. To resist these forces without specific design, **ACI 332** requires connecting the wall to the footing through use of a keyway (4.3.6.1), or dowels, and both provide adequate strength. In general, the “International Residential Code for One- and Two-Family Dwellings” (**International Code Council 2018**) permits the use of the interior concrete basement slab at the base of the wall to be sufficient for resisting these loads at the base of the wall and, in many cases, friction between the bottom of the footing and the soil or passive soil pressure on the vertical surfaces of the footing may also be sufficient to resist these loads. If there is a concern that the applied lateral loads may be unusually large, resulting in lower resistance to displacement, the design should be evaluated by a licensed design professional.

Wind loads are not generally large enough to impact the design of residential footings. Where slabs-on-grade with thickened footings exist, however, wind loads will impact the connection of the above-grade structure to the footing through anchor bolts or straps. For example, connections of a carport or open porch to the footings in a region impacted by hurricanes should be designed for uplift loads by a licensed design professional unless the local model building code includes prescriptive criteria to satisfy this loading condition. In seismic areas, a similar approach is taken to design for seismic loads, either by a licensed design professional or via prescriptive criteria.

4.3.1.3 Load determination—Figure 4.3.1.3 shows the loads for a sample structure. The “International Residential Code for One- and Two-Family Dwellings” (International Code Council 2018), ACI 332, and most model building codes provide tables for minimum footing sizes based on conservative expectations for structural loads and anticipated soil pressures. Using the load shown in Fig. 4.3.1.3, along with a building’s dimensions, the total anticipated structural load can be calculated and compared to soil-bearing capacity to determine the required footing width to distribute loads effectively.

Figure 4.3.1.3 shows a roof truss spanning the entire width of a structure and a floor system spanning from exterior wall to a central supporting wall at the midpoint of the structure. To determine the load on the exterior footing, the following are considered (assuming 18 in. [450 mm] wide footing in this example):

Roof loads:

$$60 \text{ psf snow load} \times 14.33 \text{ ft} = 860 \text{ plf, and} \\ 15 \text{ psf dead load} \times 14.33 \text{ ft} = 215 \text{ plf}$$

$$(\text{SI: } 2.87 \text{ kN/m}^2 \times 4.37 \text{ m} = 1280 \text{ kg/m, and} \\ 0.72 \text{ kN/m}^2 \times 4.37 \text{ m} = 320 \text{ kg/m})$$

First-floor loads:

$$40 \text{ psf live load} \times 14.33/2 = 287 \text{ plf, and} \\ 15 \text{ psf dead load} \times 14.33/2 = 107.5 \text{ plf}$$

$$(\text{SI: } 1.92 \text{ kN/m}^2 \times 4.37 \text{ m}/2 = 427.06 \text{ kg/m, and} \\ 0.72 \text{ kN/m}^2 \times 4.37 \text{ m}/2 = 160 \text{ kg/m})$$

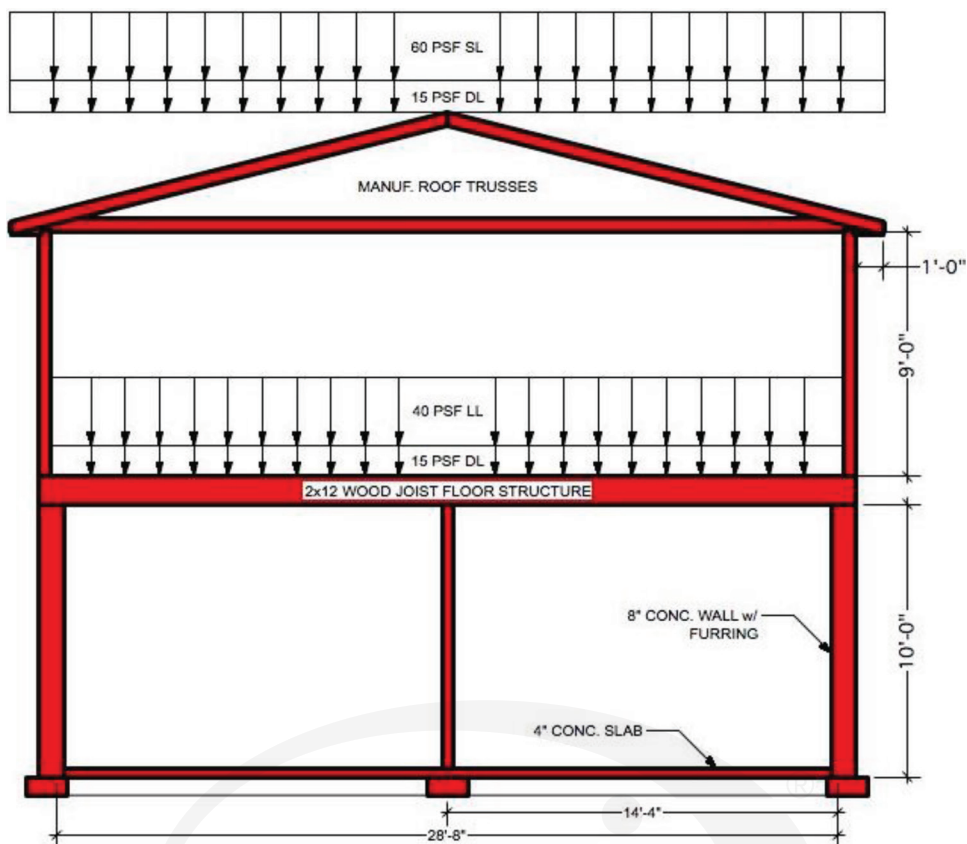


Fig. 4.3.1.3—Example calculation. (1 in. = 25.4 mm; 1 psf or lb/ft² = 0.0479 kN/m²)

Foundation wall weight:

$$8 \text{ in.}/12 \times 150 \text{ pcf} \times 10 \text{ ft} = 1000 \text{ plf}$$

$$(\text{SI: } 0.203 \text{ m} \times 2402 \text{ kg/m}^3 \times 3.05 \text{ m} = 1490 \text{ kg/m})$$

Footing weight:

$$\text{Assume } 12 \text{ in.} \times 18 \text{ in.} \times 150 \text{ pcf} = 225 \text{ plf}$$

$$(\text{SI: } 0.305 \text{ m} \times 0.457 \text{ m} \times 2402 \text{ kg/m}^3 = 335 \text{ kg/m})$$

Allowable stress design (ASD) load combinations from **ASCE/SEI 7** are checked to determine the controlling condition for applied loads through the foundation to determine the size of the footing in relation to the soil-bearing capacity. These combinations are D, D + S, D + L, and D + 0.75 (S + L). The use of all the aforementioned loads is overly conservative. Therefore:

$$\begin{aligned} D &= \text{dead weights only} \\ &= 215 + 107.5 + 1000 + 225 = 2515 \text{ plf (3724 kg/m)} \end{aligned}$$

$$\begin{aligned} D + S &= \text{dead weights + snow load only} \\ &= 215 + 107.5 + 1000 + 225 + 860 = 3375 \text{ plf (5022 kg/m)} \end{aligned}$$

$$\begin{aligned} D + L &= \text{dead weights + live loads only} \\ &= 215 + 107.5 + 1000 + 225 + 287 = 2802 \text{ plf (4169 kg/m)} \end{aligned}$$

$$\begin{aligned} D + 0.75(S + L) &= 215 + 107.5 + 1000 + 225 + 0.75(860 + 287) = 3375 \text{ plf} \\ &\quad (5022 \text{ kg/m}) \end{aligned}$$

In the aforementioned case, the D + S and the D + 0.75(S + L) are each calculated to be 3375 plf (5022 kg/m), which is the maximum for the four load combinations considered and, therefore, controls. These loads are then used to determine the required width of footing for a given soil-bearing capacity from design tables such as Table 4.3.1.3 and those found in **ACI 332** or the “International Residential Code for One- and Two-Family Dwellings” (**International Code Council 2018**). Using an assumed soil capacity of 2000 psf (9765 kg/m²), the width of the footing would be as follows:

Footing width:

$$3375 \text{ plf}/2000 \text{ psf} = 1.687 \text{ ft or } 20\text{-}1/4 \text{ in.}$$

$$(\text{SI: } 5022 \text{ kg/m}/9765 \text{ kg/m}^2 = 0.514 \text{ m})$$

The footing width was estimated to be 18 in. (450 mm) in the aforementioned example. Therefore, with a resulting width greater than that, the calculations are run again using the wider footing width. For this particular example, the result is similar with D + S and D + 0.75(S + L) having the same value (albeit slightly higher) and the footing width increasing. This process continues until the footing width and soil capacity balances.

Table 4.3.1.3—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

In general, gravity loads are assumed to be distributed linearly to the structure along the bearing conditions. 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. Usual subgrade preparation involves removing soft/compressible soil and replacing it with a compacted fill or, alternately, designing a grade beam to span over poor soil conditions. Working together, the wall and footing provide sufficient strength to properly distribute loads to the soil as described in 4.3.4.1.2.

4.3.2 Soil bearing capacity—The most influential factor on the size and performance of the footing is the soil-bearing capacity. The type of soil surrounding and supporting the

foundation may range from rock to clay to organic loams to silt as well as many variations in between. Each type of soil has a different bearing capacity based on the cohesion of particles and density of material. The performance of the subgrade may be one of the most important determinations to be made early in the project. This section discusses the issues related to making these determinations and what impacts they have on the performance of the residential foundation.

4.3.2.1 Soil-bearing pressure—Local and public records may provide data about soil type. When the soil classification is known, soil-bearing capacity (lb/ft² [kN/m²]) can be determined from either the model codes or Table 4.3.1.3.

the soil classification is not known, a licensed geotechnical engineer should perform a detailed soil investigation.

4.3.2.2 Soil testing—Soil borings for a site may be necessary to determine the soil type and properties and, therefore, the bearing capacity of the soil. Differential strata such as 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 taken for a typical house (1600 ft² [150 m²] or less), or as required by the local building official. Three or more may be required for larger commercial structures or structures with special loading or site conditions. The test locations should be selected near opposite ends of the structure or at the known location of an exterior bearing wall or anticipated point load, as illustrated in Fig. 4.3.2.2. Where penetration of the soil allows, boring depths should be at least 5 ft (1.5 m) below the anticipated depth of the bottom of the footing, or as required by the local building official. 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.

4.3.3 Footing elevation—The depth of the bottom of the footing should extend below the frost line for a specific location or otherwise be frost-protected. Local building code officials should be able to establish the prevailing frost depth for a given area. For special soils such as expansive clays, the minimum footing depth should be established so that the construction is founded on soil having a stable moisture content. Footing excavations should be carried no deeper than the anticipated bearing elevation of the footing. If footings are excavated deeper than the required thickness, additional concrete or engineered fill will be necessary to maintain the designed soil capacity of the footing condition.

4.3.4 Geometry—The configuration of a footing in terms of length, width, and height as well as other characteristics incorporating span and continuity are impacted by the configuration of the structure, the soil conditions, and the vertical loads applied through the structure. It is important to identify the physical geometry of the footings as quickly as possible in the design because the footing is the first structural component installed.

4.3.4.1 Width—The width of a footing should be based on the need for a construction platform as well as the relationship between the designed load of the structure and the bearing capacity of the soil located directly below the footing. The minimum width of the footing should always be the larger of the following two considerations.

4.3.4.1.1 Construction platform—When footings are used to provide a smooth level surface on which to construct concrete wall forms, it is important that the footing projection—the area of the footing that extends beyond both sides

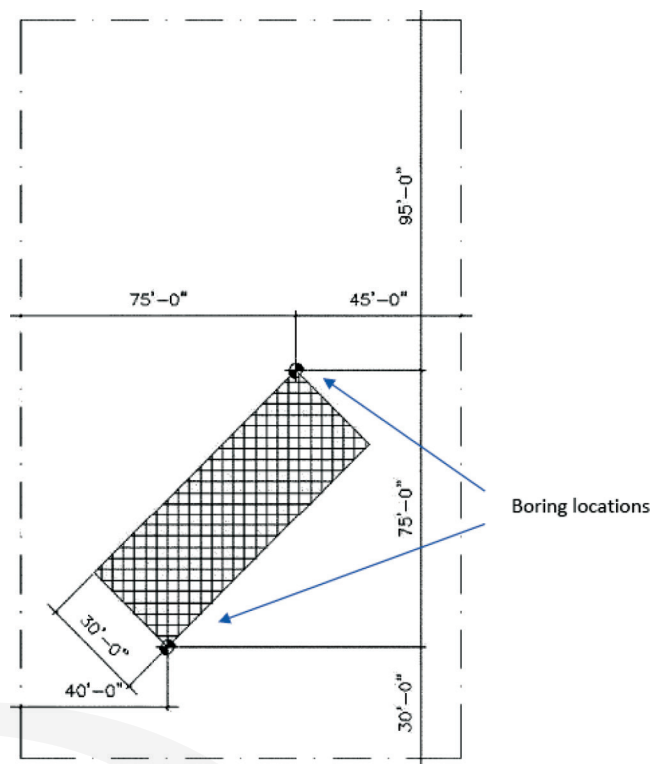


Fig. 4.3.2.2—Typical boring locations shown as circular symbols at opposite corners of building footprint as denoted by crosshatched area. (Note: 1 in. = 25.4 mm.)

of the foundation wall—be wide enough to accommodate the proposed wall forming system, as shown in Fig. 4.1. Typically, a 2 in. (50 mm) projection on each side of the proposed wall is sufficient.

4.3.4.1.2 Transfer of loads to soil—Footing width determines how large of an area the designed vertical load is transferred across. Increasing footing width increases the bearing surface of the footing and dissipates the load across a larger area, thus reducing the bearing pressure at any given location, reducing the possibility of settlement in the final structure. To successfully transfer the building loads to the supporting soil condition, the footing should be of sufficient width to ensure the soil capacity across the area of contact is higher than the applied loads. In some regions, soil capacities can be very low, sometimes 1200 lb/ft² (57 kN/m²) or less, and resulting footing widths will be quite large. Usual subgrade preparation involves removing soft/compressible soil and replacing it with a compacted fill or, alternately, designing a grade beam to span over poor soil conditions. Working together, the wall and footing provide sufficient strength to properly distribute loads to the soil, as described in 4.3.4.1.2. Where soil conditions are good (usually 2000 lb/ft² [96 kN/m²] and higher soil bearing), the width of the footing is likely to be no more than 4 to 6 in. (100 to 150 mm) greater than the width of the supported foundation wall to be sufficient for the soil-bearing capacity to transfer the applied vertical loads to the soil in residential structures. In some cases, however, the soil may be closer to that of rock and may have capacities of 7500 lb/ft² (300 kN/m²) or more, resulting in footing widths that are not greater

than the thickness of the supported wall. The “International Residential Code for One- and Two-Family Dwellings” (International Code Council 2018) or ACI 332 provides the minimum required footing widths based on commonly tabulated residential loads and soil capacities. Using these tables, conditions of increasing applied load can be addressed by increasing the width of the footing, which results in a larger area for distribution of the loads.

4.3.4.2 Thickness—The minimum footing thickness (also referred to as depth of footing) is often determined by the footing width. The typical footing thickness is 8 to 12 in. (200 to 300 mm) for basic residential structures. Footing projections typically support the forming system and should not exceed the footing thickness as illustrated in Fig. 4.2.1a. Both the “International Residential Code for One- and Two-Family Dwellings” (International Code Council 2018) and ACI 332 permit a footing thickness of 6 in. (150 mm), provided the footing projection on either side of the wall does not exceed 6 in. (150 mm).

4.3.5 Steps—When the design of a foundation wall calls for the bottom elevation to change, the condition is commonly referred to as a step (Fig. 4.3.5). For these conditions, it is often possible for the continuous footing to be interrupted or stopped and then restarted at the lower or higher elevation. As detailed in ACI 332, the footing may be terminated at both sides of the elevation change, provided the wall is designed to act as a beam, spanning the separation distance between footings, and transferring all applied loads to those footings on either side. There are many conditions where footing steps may be required or advantageous, both in plane and out of plane, such as a garage foundation wall perpendicular to the basement foundation wall. The use of this step design or discontinuous footing more effectively uses the structure of the concrete wall, which can span the footings. Consideration should be made for the forming module if possible, to maximize the efficiency of the construction.

4.3.6 Lateral restraint—Although the “International Residential Code for One- and Two-Family Dwellings” (International Code Council 2018) permits the interior slab to be considered adequate restraint at the base of the foundation wall, it is most often not present at time of backfill and, therefore, not able to prevent movement of the wall during backfilling. Therefore, it is important to determine the use of keyways or dowels as the shear connection between the footing and foundation wall.

4.3.6.1 Keyways—Keyways (Fig. 4.3.6.1a and 4.3.6.1b) are one method permissible by ACI 332 to resist lateral load at the bottom of the wall. The keyway creates a mechanical connection between the footing and base of foundation wall for this purpose. Keyways may be formed using a reverse bevel-cut two-by-four or by removing material from the center of the 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 approximately 1-1/2 in. (38 mm) deep by 1-1/2 in. (38 mm) wide at the top of the footing.

4.3.6.2 Dowels—Steel dowels are also permissible by ACI 332 for lateral force resistance and are a more common



Fig. 4.3.5—Discontinuous footing at a common wall step.

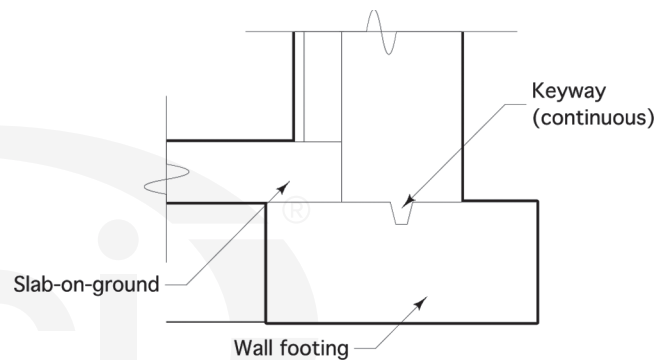


Fig. 4.3.6.1a—Keyway detail.



Fig. 4.3.6.1b—Footing with formed keyway.

component in footing construction, extending from the footing into the wall. They are an alternative to keyways for shear transfer (Fig. 4.3.6.2a and 4.3.6.2b). Dowels are typically 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

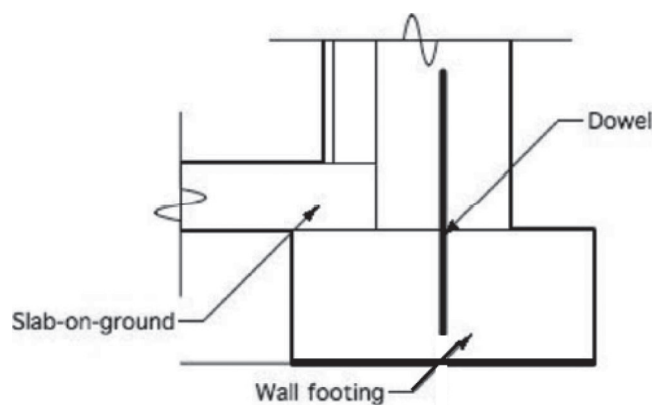


Fig. 4.3.6.2a—Steel dowel shear connection.



Fig. 4.3.6.2b—Footing with dowels.

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 secured to the formwork before concrete placement to maintain their vertical and horizontal positions as well as alignment.

Where the foundation wall requires vertical reinforcement, this reinforcement embedded into the footing or lapped into the footing may also be used to provide shear transfer and serve as this dowel connection, provided the spacing is sufficient.

4.3.7 Concrete

4.3.7.1 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 reinforcement is required.

4.3.7.2 Slump—In general, slump for concrete used in footings should not exceed 6 in. (150 mm); however, concrete containing a high-range water-reducing admixture (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



Fig. 4.3.8.1a—ICF stem wall with bag footing being poured concurrently with steel fiber-reinforced concrete.

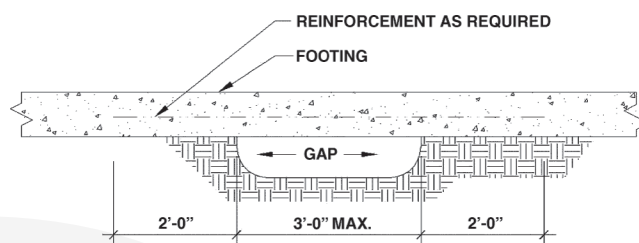


Fig. 4.3.8.1b—Footing spanning gap. (Note: 1 in. = 25.4 mm.)

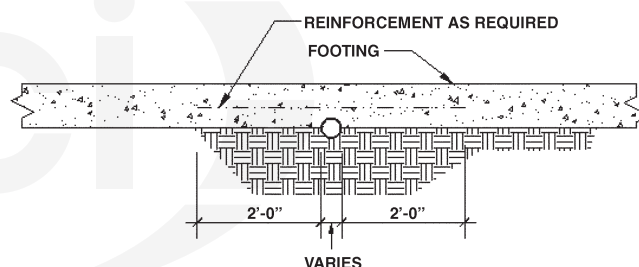


Fig. 4.3.8.1c—Penetration or reduced thickness of a concrete footing and required reinforcement. (Note: 1 in. = 25.4 mm.)

can result in honeycombing and weakened zones that may require costly repair or removal and replacement.

4.3.8 Reinforcement

4.3.8.1 Purpose—Footings can contain reinforcement, whether designed as plain concrete members or reinforced concrete members. Steel reinforcement in footings may consist of reinforcing bars placed longitudinally, transversely, or both, to the direction of the footing or steel fibers mixed randomly with the concrete. The use of steel fibers in residential footing construction has been steadily increasing to completely replace reinforcing bar or combined with reinforcing bar to provide the load-carrying capacity of the footing, as shown in Fig. 4.3.8.1a.

Longitudinal reinforcement is sometimes used to bridge soft spots and minor trenches or to increase strength over narrow excavations, as shown in Fig. 4.3.8.1b and 4.3.8.1c, respectively, in accordance with ACI 332. Footings that span trenches or poor soil veins below the footing are typically reinforced with longitudinal bars that extend 6 in. (150 mm) beyond the edges of the maximum soil condition. Similarly,

if a through-footing penetration interrupts footing continuity, it may be reinforced similarly to a span condition. This would require that the continuous section be thick enough for cover requirements. Alternately, the foundation wall may be reinforced to span the discontinuity, as noted in **ACI 332**. Transverse footing reinforcement is typically not required unless the width-to-depth ratio of the footing exceeds 2 to 1 or it is specified by the licensed design professional.

4.3.8.2 Grade and size—Residential construction practice typically involves the use of standard steel reinforcement of **ASTMA615/A615M** Grade 40 and 60 (Grade 280 and 420). Number 4 and 5 (No. 13 and 16) deformed steel bars are the most commonly used. The grade is related to the tensile capacity of the steel used in the bars (for example, Grade 60 equals 60,000 psi tensile strength [Grade 420 equals 420 MPa]). ACI 332 provides design tables for footings based on both common grades. Higher-strength steel is beginning to appear on the market and a licensed design professional should be consulted to modify the requirements of those tables for the higher available strengths.

4.3.8.3 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. If permitted by the licensed design professional, 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. Where bar lengths meet, they are typically required to overlap a distance of 30 bar diameters ($30d_b$) or 24 in. (610 mm), whichever is greater, as shown in Fig. 4.3.8.3.

4.4—Footing construction

4.4.1 Excavation—Once the excavation has been made for the house foundation, the contractor will typically come back and excavate for the footing depth from the undisturbed earth. The new bottom of the footing surface is considered undisturbed earth and the thickness of the footing excavation is generally the footing thickness unless the contractor will use forming for all or a portion of the footing thickness.

4.4.1.1 Poor soils—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. Therefore, areas of fill below footings should be avoided when possible or limited to the available span capacity of the footing design per ACI 332. Where larger areas of fill are unavoidable, granular fill (sand, lime, or gravel) should be used and compacted to meet the specified bearing capacity. Controlled low-strength materials (CLSMs), 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.

4.4.1.2 Compromised excavations—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

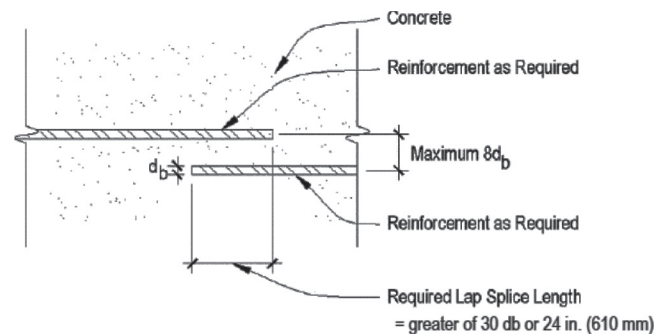


Fig. 4.3.8.3—Lap splice requirements for footing and foundation wall reinforcement.

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.

4.4.1.3 Frost depth—Building codes require the depth of the bottom of the footing to extend below the frost line for a specific 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 required depth thickness, they should either be filled with additional concrete, or engineered fill will be necessary to maintain the designed soil capacity of the footing condition.

4.4.2 Forming methods—Footings may be fully formed, trench-formed, free-formed, or a combination of these methods. **ACI 347R** and **ACI SP-4** can provide guidance for the selection of forming systems and the specific requirements for each type.

4.4.2.1 Fully formed footings—Fully formed footings require excavation wider than the footing itself. Footing forms made of wood, metals, plastic, or alternative products are then set to height and concrete is poured inside them.

4.4.2.1.1 Wood forms—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. 4.4.2.1.1).

4.4.2.1.2 Metal forms—Steel or aluminum (Fig. 4.4.2.1.2) 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 react due to the high pH of concrete, 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.

4.4.2.1.3 Alternative forming materials—Manufactured forming systems made of metal fabrics, synthetic fabrics