

Chapter 3

FOUNDATIONS AND FOUNDATION WALLS

This chapter discusses foundations and foundation walls constructed using the two most common foundation materials – concrete and masonry. Although the *IRC* permits the use of treated wood for foundations and foundation walls and insulating concrete form (ICF) for foundation walls, this guide does not cover those materials other than to inform the reader that wood foundations in Seismic Design Categories (SDCs) D₁ and D₂ require engineering design and many of the reinforcement requirements for concrete also apply to ICF (see Chapter 4 of the *IRC* for more information on the use of these materials). The subject of frost protection of foundations also is not discussed in this guide but, where required by the code (see *IRC* Section R403.1.4.1) or local regulations, foundations must either extend below the frost line or be protected from frost using approved methods.

3.1 GENERAL FOUNDATION REQUIREMENTS

Foundations are the interface between a house and the supporting soils. Many issues must be considered when selecting a foundation system including site topography, soils conditions, retaining requirements, loading from the house above, frost depth, and termite and decay exposure. Foundations primarily provide support for vertical gravity loads from the weight of a house and its contents, but they also provide resistance to horizontal sliding resulting from earthquake ground motions and must resist vertical loads at the ends of braced walls. Regardless of Seismic Design Category, all houses require a continuous foundation extending at least 12 inches below undisturbed soil along all exterior walls as shown in Figure 3-1.

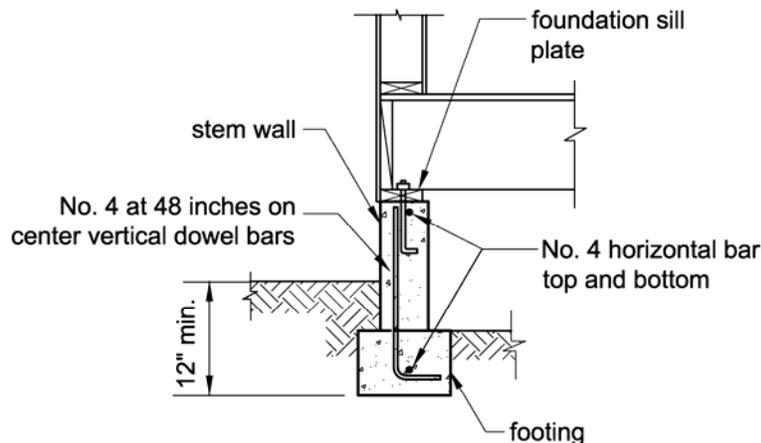


Figure 3-1 Perimeter foundation with separately placed footing and stem wall.

When earthquake ground motion occurs, the resulting ground movements, velocities, and accelerations are imparted to the foundation and, in turn, transferred to a house or other building. How well the house performs during an earthquake depends on the foundation being able to provide:

- Continued vertical support,
- Friction and passive bearing at the soil-to-foundation interface to minimize movement and damage,
- Anchorage at the foundation-to-house interface to minimize movement and damage, and
- Strength and stiffness sufficient to resist both horizontal loads and vertical loads resulting from racking and overturning of bracing walls within the house.

The foundation of the house must resist the sliding and overturning actions associated with an earthquake. These two actions are illustrated in Figures 3-2 and 3-3. The soil surrounding a foundation can resist sliding using a combination of friction along the bottom and bearing along the sides of the foundation; therefore, a wider and deeper foundation provides greater friction and greater bearing resistance than a shallow and narrow foundation. The whole overturning action illustrated in Figure 3-3 is resisted at the foundation in two ways. The portion of the foundation being pushed downward will bear against the soil below so a wider footing will provide more surface area to resist that downward load. At the uplift end of the foundation, the weight of any soil located above a footing helps to resist the loads trying to pull the foundation out of the ground; therefore, a deep inverted T-shaped foundation will provide greater resistance to uplift than a shallow footing or than a foundation having a shape that avoids having any soil above the top of the footing.

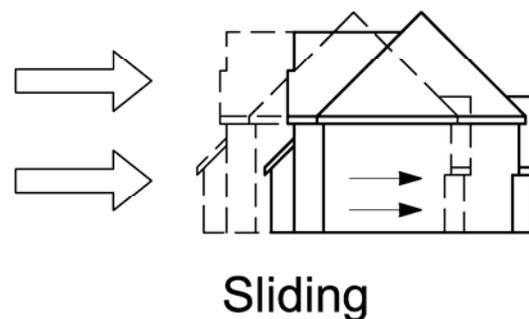


Figure 3-2 Sliding action resisted by foundation.

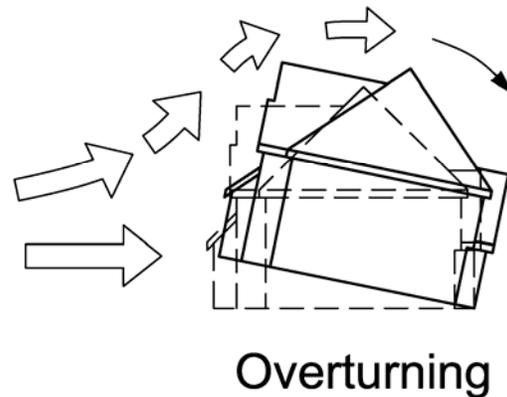


Figure 3-3 Overturning action resisted by foundation.

The *IRC* discusses foundations (footings and stem walls) and foundation walls separately and contains requirements for those elements based on the materials used for their construction. This guide chapter is similarly organized and addresses foundations placed monolithically with a slab on grade and foundations having a combination footing and stem wall as illustrated in Figure R403.1(1) of the *IRC*. Foundation systems such as pilings, drilled piers, and grade beams require the involvement of a licensed design professional and are not discussed in this guide.

IRC foundation wall provisions have evolved from similar provisions in the *CABO One- and Two-Family Dwelling Code* and *Standard Building Code*. Neither the *IRC* nor the other building codes give definitive guidance on when to use the foundation wall provisions of *IRC* Section R404 rather than the footing stem wall provisions of *IRC* Section R403. The 2000 *IRC Commentary* notes that the foundation wall provisions are primarily for masonry and concrete basement walls. The provisions of *IRC* Section R404 become mandatory for wall heights of 5 feet and greater and for walls retaining unbalance fill of 4 feet or greater. For wall heights and unbalanced fill heights less than this, there are few practical differences between the foundation and foundation wall provisions.

IRC Section R403.1.2 contains a general rule applicable to buildings located in SDCs D_1 and D_2 that requires interior braced wall lines to be supported on a continuous foundation when the spacing between parallel exterior wall lines exceeds 50 feet. However, *IRC* Section R602.10.9 contains a slightly more restrictive requirement. For a two-story house in SDC D_2 , a continuous foundation is required below all interior braced walls, even when the distance between exterior walls does not exceed 50 feet, unless three additional conditions can be met. Those conditions are:

- The distance between braced wall lines does not exceed twice the building width measured parallel to the interior braced wall line;
- In houses having either a crawl space or basement, cripple walls cannot exceed 4 feet in height; and

- In houses having a crawl space or basement, first-floor interior braced walls are supported on double joists, beams, or blocking as shown in Figure 3-4.

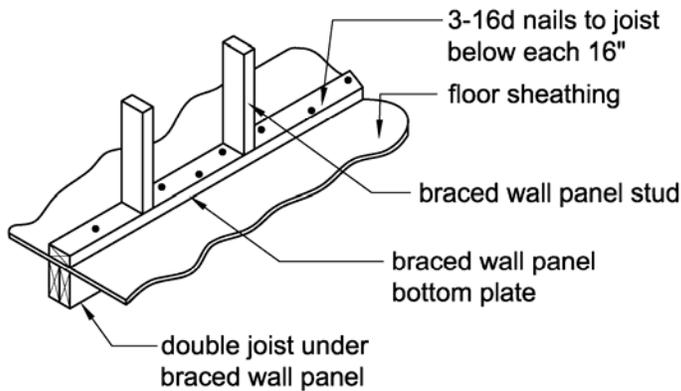


Figure 3-4 Interior braced wall on floor framing.

Above-code Recommendation: The main consequence of not providing a continuous foundation below a first-story interior braced wall line is that the floor must be strong enough to transfer earthquake loads from that interior location to a parallel perimeter foundation. This transfer of lateral loads can be accomplished using a wood-framed and -sheathed floor system, but this solution will definitely impart additional stresses in the floor and into cripple walls at the perimeter that would not occur if a foundation was provided below the interior braced wall line. Vertical loads due to the overturning loads in the braced wall segments also must be transferred to the perimeter foundation through bending action. **While the doubling of the floor joist is an improvement, supporting these walls directly on a continuous foundation is recommended to achieve above-code performance.**

For slab-on-grade construction in SDCs D₁ and D₂, when the conditions described above require an interior braced wall line to have a foundation, the foundation depth along that interior wall must be at least 18 inches below the top of the slab as shown in Figure 3-5.

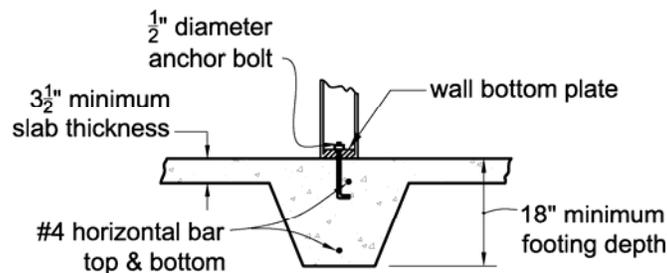


Figure 3-5 Foundation requirements for interior braced wall line on slab-on-grade construction.

3.2 CONCRETE FOUNDATIONS

Regardless of Seismic Design Category, the minimum specified concrete strength for foundations (and foundation walls) is 2,500 pounds per square inch (psi) with higher strength necessary when a foundation is exposed to the weather and the house is located in a moderate or severe weathering probability area as shown in *IRC* Figure R301.2(3). Specifying 2,500 psi refers to a measure of the concrete's compressive strength. To enable a concrete foundation to resist all of the possible loads to which it may be exposed, compressive strength needs to be complimented with tension capacity. Since concrete is unable to resist tension stresses without cracking, steel reinforcing bars are added to resist tension. Reinforcing is particularly valuable when resisting cyclic earthquake loads because, within the span of a few seconds, the loads may start by causing compression and then reverse to cause tension in the same location.

IRC Section R403.1.3 specifies minimum reinforcement of concrete footings located in SDCs D₁ and D₂. Separate subsections within *IRC* Section R403.1.3 address reinforcing of foundations consisting of a footing and a stem wall and reinforcing of the footing along the perimeter of a slab-on-grade. *IRC* Section R403.1.3 also contains an exception that allows omitting the longitudinal reinforcing in concrete footings for houses that are three stories or less in height and constructed with stud walls, regardless of the Seismic Design Category.

Above-code Recommendation: To obtain above-code performance in SDC C, it is recommended that the minimum foundation reinforcing requirements for SDCs D₁ and D₂ be used. This added reinforcing will provide better footing performance whether it is resisting earthquake loads or loads induced by differential soil settlement, expansive soils, or frost heave.

Typically, the bottom portion of a concrete footing must have one horizontal No. 4 reinforcing bar located 3 inches up from the bottom of the concrete (clear from the soil along the bottom of the footing). When a foundation consists of both a footing (horizontal foundation segment) and short stem wall (vertical foundation segment), two No. 4 continuous horizontal reinforcing bars are required – one in the bottom of the footing and one near the top of the stem wall as shown in Figure 3-6.

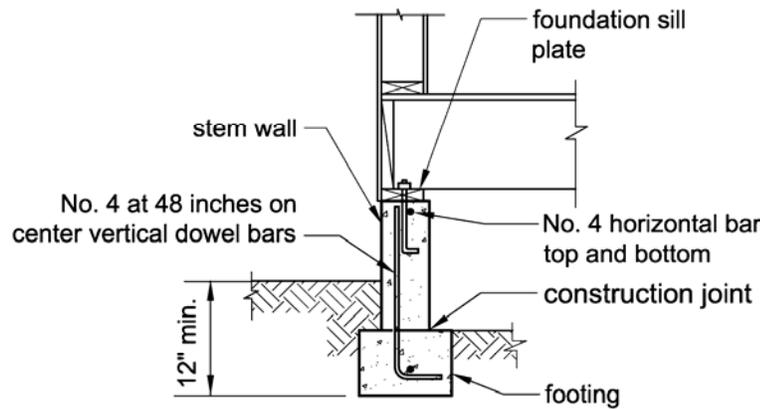
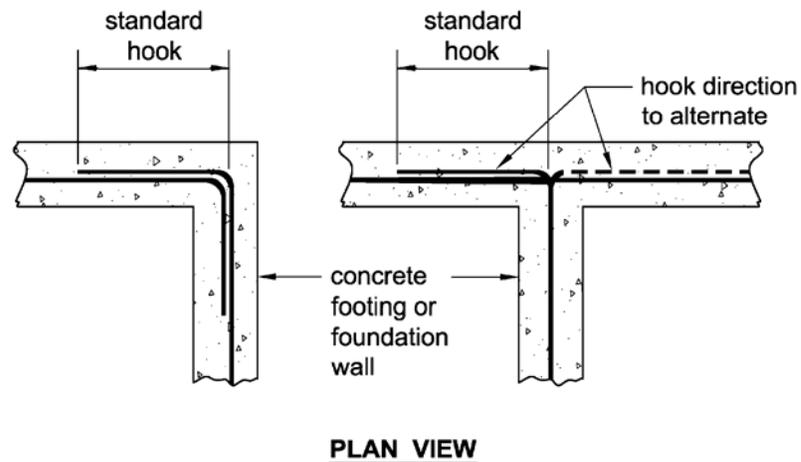


Figure 3-6 Recommended minimum reinforcement for concrete footings and stem walls.

Above-code Recommendations: When horizontal reinforcing bars are used in foundations, they need to be continuous to perform their intended function. The *IRC* does not provide any specific guidance on reinforcing continuity; therefore, the following **above-code** recommendation is derived from the basic standard for concrete construction (ACI 318-02, 2003). **Where two or more pieces of reinforcing steel are used to provide continuous horizontal reinforcing, the ends of the bars should be lapped to provide continuity. The minimum recommended lap for No. 4 bars is 24 inches and for No. 5 bars is 30 inches. As shown in Figure 3-7, horizontal bars terminating at corners of perimeter foundations and where an interior foundation intersects a perimeter foundation should have a standard 90-degree hook of 8 inches for No. 4 bars or 10 inches for No. 5 bars.**



PLAN VIEW

Figure 3-7 Above-code horizontal reinforcing lap at corners and intersections.

In SDCs D₁ and D₂, No. 4 vertical reinforcing is required at 48-inch maximum spacing if a construction joint (also called a “cold joint”) occurs between the footing and the stem wall. This often is referred to as a “two-pour” foundation because the concrete for the footing and the concrete for the wall are poured at separate times. These vertical bars (also called “dowels”) must extend a minimum of 14 inches into the stem wall and be hooked at the bottom into the footing as shown in Figure 3-6. These dowels provide a very important connection because, without them, earthquake loads can cause sliding to occur along the joint between the two separate concrete placements. Sliding along a similar construction joint between a slab-on-grade and a separately poured footing below the slab edge occurred during the 1994 Northridge earthquake and caused severe damage in houses located in Simi Valley, California.

When a house has a concrete slab-on-grade with a thickened edge forming its perimeter foundation (also called a “turned-down slab edge”), one No. 4 horizontal reinforcing bar is required in the top and bottom of this footing as shown in Figure 3-8. The exception to this is when the slab and footing are poured at the same time; in this case, a single No. 5 bar or two No. 4 bars located in the middle third of the combined slab and footing depth may be used. For slab-on-grade construction in SDCs D₁ and D₂, interior bearing walls and interior braced walls required to have a continuous foundation must have the concrete slab thickened to 18 inches to form a foundation as shown in Figure 3-5.

Above-code Recommendation: Although the *IRC* is basically silent on how to reinforce these interior thickened slab foundations, it is recommended that they should be reinforced as described above for the foundation along the slab perimeter. Horizontal reinforcing in slab-on-grade foundations should be continuous as described earlier.

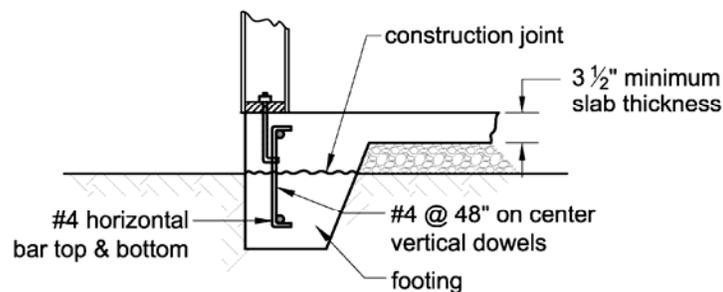


Figure 3-8 Above-code use of vertical dowels to connect a slab-on-grade to a separately poured footing.

Above-code Recommendation: When a slab-on-grade is poured separately from the footing below, the *IRC* does not specify any vertical reinforcing across this joint. When this condition occurs, however, the possibility of earthquake loads causing sliding along that joint is very real. The basic provisions of ACI 318-02, Sec. 11.7.9, for concrete require that all construction joints be provided with a mechanism for transferring loads through the joint. **Therefore, it is recommended that the same amount of vertical reinforcing required for a separately poured stem wall and footing condition (No. 4 at 48 inches on center) be installed to connect a slab to a separately poured footing as shown in Figure 3-8. In addition the surface of the construction joint should be cleaned to remove loose debris prior to placing the concrete slab.**

Above-code Recommendation: Anchor bolts connecting a wood sill plate to a foundation also must be installed in the foundation or stem wall. **Although it is possible to install anchor bolts during the placement of the foundation concrete before it has hardened (also called “wet setting”), this is not recommended. Anchor bolts should be installed and secured so that they will not move prior to placing the concrete.** The reason is that a wet setting can create a void in the concrete adjacent to the bolt. Anchor bolts, whether they have heads or hooks on the embedded end, will either make a hole or carve a slot as they are pushed into the wet concrete. That hole or slot forms a void over the entire length of the bolt’s embedment. This void prevents the bolt from completely bearing against the surrounding concrete and could result in movement of the bolt when subjected to earthquake loads. Additional anchor bolt requirements are provided at the end of this chapter.

3.3 MASONRY FOUNDATIONS

Masonry foundation requirements are generally more dependent upon the Seismic Design Category of the site than concrete foundation requirements. Solid clay masonry or fully grouted concrete masonry and rubble stone masonry may be used for foundations in SDCs A, B, and C; however, rubble stone masonry is not allowed in SDCs D₁ and D₂ due to its relatively low strength and stability.

Above-code Recommendation: **Because of their relatively low strength and stability, rubble stone foundations are not recommended for use in SDC C as an above-code measure.**

Above-code Recommendation: Like concrete, a masonry foundation with a stem wall must have at least one No. 4 horizontal bar in the bottom of the footing and one No. 4 bar near the top of the stem wall. This horizontal reinforcing needs to be continuous just as it does in concrete construction. **Therefore, the above-code recommendations for lap splices are 24 inches for No. 4 bars and 30 inches for No. 5 bars with hook extensions at corners as shown in Figure 3-7.**

In SDCs D₁ and D₂, masonry stem walls also must have vertical reinforcing and must be grouted as required by *IRC* Sections 606.11.3 and 606.12. (See Chapter 6 of this guide for a more detailed discussion of grouting in masonry wall construction.) For a masonry stem wall supported on a concrete footing, the vertical reinforcing must be one No. 4 bar at 48-inches maximum spacing, extending into the footing with a standard hook at the bottom, similar to what is shown in Figure 3-6. This is necessary to prevent sliding along the bottom mortar joint between the concrete footing and the masonry stem wall.

Above-code Recommendation: In order to prevent sliding along the bottom mortar joint between the concrete footing and the masonry stem wall, it is recommended that masonry stem walls in SDC C also use the vertical reinforcing required in SDCs D₁ and D₂.

3.4 FOOTING WIDTH

Footing width is not dependent upon Seismic Design Category but instead is solely based on vertical load considerations. The minimum width for a concrete or masonry footing is dependent on the load bearing capacity of the soil measured in pounds per square foot (psf) and the number of stories and the weight of the wall it supports. For instance, when brick veneer is installed, this added weight requires a wider footing.

The minimum soil bearing capacity considered by the *IRC* is 1,500 psf. In this case, the minimum footing width is 12 inches but it can increase to as much as 32 inches for a three-story house with brick veneer as shown in Figure 3-9.

Bearing capacity is determined based on the soil classification determined for the site. Soil classifications and corresponding bearing capacities are listed in *IRC* Table R401.4.1 at the beginning of *IRC* Chapter 4. The soil classification system is described in *IRC* Table R405.1. There are four distinct groups of soils that comprise a total of 15 separate soil classifications ranging from well graded gravels as the best and peat as the worst. Accurate determination of soil bearing capacity requires correct classification of the soil at the building site and may require the expertise of a soils engineer or geologist. However, most building departments have determined the soil classification for most of the sites within their jurisdiction. Accurate determination of the correct site soil classification is important not just for determining the minimum footing width but also for determining the minimum reinforcing required for concrete or masonry foundation walls.

When a footing is constructed with a width at the bottom that is greater than the thickness of its stem wall or a width greater than the thickness required for a foundation wall (e.g., an inverted-T shape), the minimum thickness of the footing is 6 inches. *IRC* Section R403.1.1 also specifies both a minimum and maximum width for the footing portion of this inverted-T foundation. As a minimum, the projection of the vertical face of the footing must be at least 2 inches beyond each vertical face of the stem wall or foundation wall. The maximum projection may not exceed the thickness of the footing. These dimensional requirements for an inverted-T foundation are illustrated in Figure 3-9. These minimum and maximum projection limits of the footing beyond the stem wall are consistent with ACI 318 design of plain concrete footings. Based on those requirements, an L-shaped footing should not be permitted unless its dimensions and reinforcing are designed to account for the eccentricity of the vertical load on the footing.

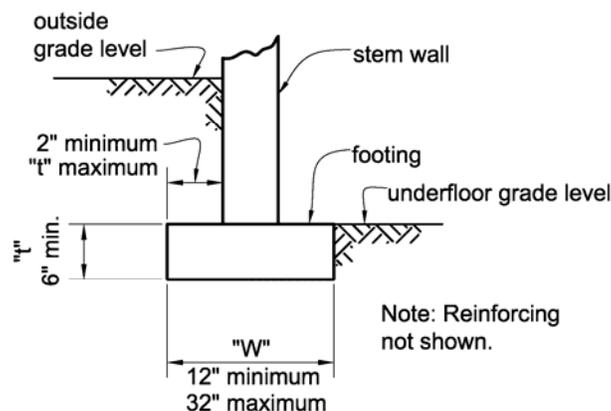


Figure 3-9 Inverted -T footing dimensions.

3.5 SPECIAL SOIL CONDITIONS

On some sites, such as those in marshy areas or bogs, the bearing capacity of the soil may be known or suspected to be less than 1,500 psf. In such a case, the *IRC* requires a soil investigation and report to determine the actual bearing capacity of the soil and to define an appropriate footing width and depth. Soil testing also is necessary when it is likely that existing soil has shifting, expansive, compressive, or other unknown characteristics. Local officials often are aware of such conditions in locations where previous buildings have been constructed and may have maps identifying such areas and/or special rules that apply to foundation construction in such areas. When existing soil data are not available, such as on previously undeveloped sites, it is always prudent to obtain tests to validate bearing capacity and to determine if expansive soils are present.

When expansive soils that exhibit large changes in volume (usually in response to changes in moisture content) are encountered, foundations must be designed in accordance with *IBC*

Chapter 18 because the prescriptive requirements of the *IRC* assume no such special conditions are present. Methods to address expansive soil include foundation designs to resist the stresses caused by the soil volume changes that are likely to occur, isolation of the foundation, removal of the expansive soil, or stabilization of the soil by chemical, dewatering, presaturation, or other methods. Failure to identify and adequately compensate for differential movements caused by expansive soils can result in excessive stresses on the foundation causing cracking of even reinforced concrete or masonry foundations. Foundation movement induced by expansive soil also can result in differential movement of the house's wood framed walls that can crack brick, gypsum wallboard, and stucco finishes. Movement of the walls can create stresses that loosen the nailed connections of wall sheathing used to provide lateral bracing. These effects can, in turn, weaken a building's earthquake resistance so it is very important to address expansive or other special soil conditions to limit differential foundation movement.

3.6 FOUNDATION RESISTANCE TO SLIDING FROM LATERAL LOADS

Foundations are the final link in the load path within a building to transfer the earthquake loads to the ground. At the foundation level, the combined lateral loads from the entire building are attempting to push the building laterally. To resist movement, the foundation pushes against the soil that surrounds it. Consequently, footing width and depth are factors that determine the resistance that can be provided by the foundation to earthquake ground motions. This is because footing width determines the horizontal surface area of the bottom of a foundation in contact with the ground and the depth determines the vertical surface area bearing against the soil on either side. These surface areas provide resistance to sliding through a combination of friction and bearing against the soil as shown in Figure 3-10. Therefore, a wider or deeper foundation will be capable of resisting greater lateral loads than a narrower or shallower foundation. Similarly, the sliding resistance of a slab-on-grade house will be greater than that of one having only a perimeter foundation due to the added frictional surface area provided by the underside of the slab.

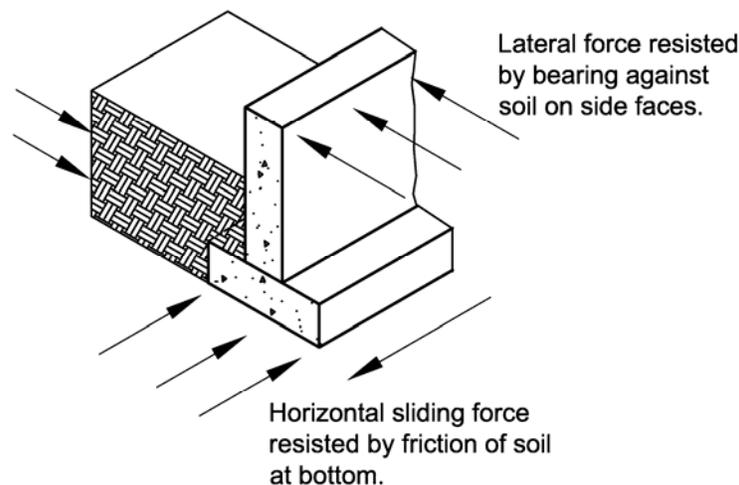


Figure 3-10 Lateral resistance provided by foundation.

Above-code Recommendation: For houses with the first floor located above a crawl space rather than a basement, *IRC* Section 408.5 allows finished grade under the floor to be located at the bottom of the footing except where the groundwater table is high, surface drainage is poor, or the area is prone to flooding. However, when the finished grade is located at the bottom of the footing, the vertical face of the footing on that side does not bear against soil. **Therefore, as an above-code measure, in SDCs D₁ and D₂, it is recommended that crawl space perimeter footings have their entire depth below the finished grade of the crawl space.** Embedment along both vertical faces of the footing provides additional bearing surface area to resist sliding loads perpendicular to the exterior walls.

Above-code Recommendation: To aid in providing sliding resistance, the bottom of footings should be level. The *IRC* does allow the bottom of footings to be sloped at a rate of not more than 1 foot vertical in 10 feet horizontal. When this maximum slope along the bottom of the footing cannot be met, the bottom must be stepped. Similarly, the top of foundations must be level but can also be stepped. **As an above-code measure when steps are used, the horizontal reinforcing should be bent to extend through the steps as shown in Figure 3-11.**

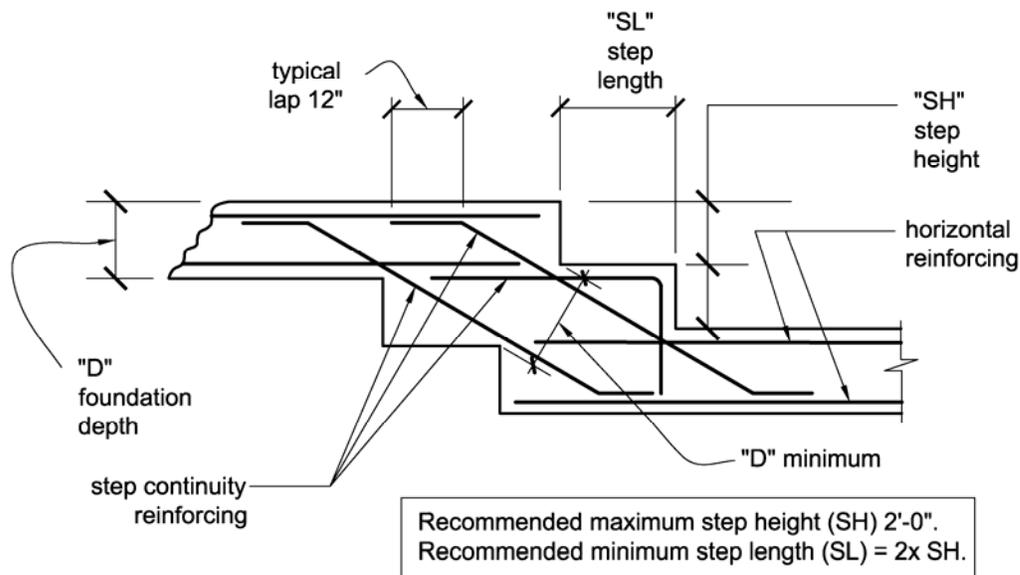


Figure 3-11 Above-code stepped foundation reinforcing detail.

Above-code Recommendation: Special consideration also must be given to sites where the ground slopes upward or downward beyond the limits of the perimeter foundation to ensure that adequate resistance to foundation sliding and settlement are provided and to protect against the effects of drainage, erosion, and shallow failures of the sloping surface. Prescriptive rules for setbacks from either an ascending or descending slope are given in *IRC* Chapter 4. Smaller (or greater) setbacks may be approved (or required) based on a soil investigation report prepared by a qualified engineer. **Because landslides can be triggered by earthquakes, any building site having natural or man-made sloping terrain above or below should be thoroughly evaluated for landslide potential even when the prescriptive setbacks of the code are met.**

3.7 SPECIAL CONSIDERATIONS FOR CUT AND FILL SITES

A hillside site can result in foundations being supported on soils having very different bearing capacities. Figure 3-12 shows a situation where a portion of the foundation is supported on rock and the other side is supported on a fill that extends above the existing rock grade. This condition often occurs when soil is removed (cut) from the high side of a lot and the lower side has fill material installed to create a level building pad. Although the *IRC* requires all fill soils to be designed, installed and tested in accordance with accepted engineering practice, there is no specific guidance given in the *IRC* regarding what should be addressed. Site-specific guidance on the design and placement of fill material is a particularly important concern in high seismic areas.

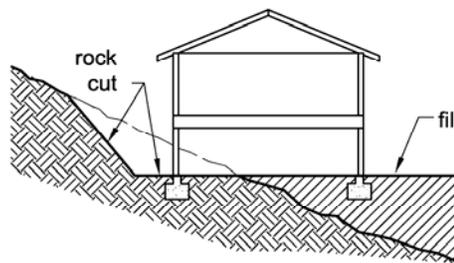


Figure 3-12 Foundation supported on rock and fill.

Studies of damage to houses located on cut and fill sites as a result of the 1971 San Fernando (McClure, 1973, Slosson, 1975) and the 1994 Northridge (Stewart, et al., 1994 and 1995) earthquakes document the consequences of improperly installed and compacted fill. Figure 3-13 shows an example of the type of damage that occurred to slab-on-grade houses during the Northridge earthquake. Generally, these sites experienced settlement and extension of the fill portion of the site and vertical displacement along the line of transition from cut to fill.

Above-code Recommendation: To meet the intent of the *IRC* requirement for all fill soils to be designed, installed and tested in accordance with accepted engineering practice, it is recommended that the reporting requirements conform to those specified in *IBC* Section 1803.5.



Figure 3-13 Example of damage caused in building on cut and fill site.

Above-code Recommendation: Even with proper installation and compaction of engineered fills, earthquakes are expected to result in some differential settlement and consequent damage when a house has a portion of its foundation on a cut pad and other portions on fill. **Therefore, in SDCs C, D₁ and D₂, sites that require a cut and fill approach should be avoided, particularly if a slab-on-grade foundation is used. Where cut and fill grading of a site is unavoidable, increased levels of quality control should be used to ensure the optimum installation of the fill, and foundations should be designed to either accommodate or resist the expected settlement.**

3.8 FOUNDATION WALLS

Foundation walls are typically basement walls but also include foundation stem walls that extend from the top of a footing to the bottom of a wood framed floor and enclose a crawl space as shown in Figure 3-6. Depending on the difference in ground level on each side of a foundation wall, certain minimum requirements for reinforcing and wall thickness will apply. Foundation wall construction is dependent to some extent on Seismic Design Category, particularly for SDCs D₁ and D₂ sites.

Foundation walls can be constructed of concrete, masonry, or preservative-treated wood or by using insulating concrete form (ICF) systems. As mentioned earlier, treated wood systems are not discussed in this guide. ICF foundation walls are likewise not discussed because *IRC* Section R404.4.1 limits use of ICF foundation walls to SDCs A, B and C; however, future *IRC* editions may allow adequately reinforced ICF foundation walls in SDCs D₁ and D₂ if proposed code changes on this subject are approved. Rubble stone masonry foundation walls also are not permitted in SDCs D₁ and D₂ for reasons similar to those that prohibit this material's use as a footing in SDC D₁ and D₂.

Regardless of Seismic Design Category, all foundation walls must extend a minimum of 6 inches above the adjacent grade or, when brick veneer is used on a wall, the foundation wall must extend a minimum of 4 inches above the adjacent grade.

Concrete and masonry foundation walls must conform to the prescriptive requirements of the *IRC* or may be based on other recognized structural standards such as ACI 318 for concrete or either NCMA TR68-A or ACI 530/ASCE 5/TMS 402 for masonry. When concrete or masonry walls are subject to hydrostatic pressure from groundwater or support more than 48 inches of unbalanced fill, without permanent lateral support at the top and bottom, they must be designed using accepted engineering practice. The discussion below relates only to the *IRC* prescriptive methods for concrete or masonry foundation walls.

Several terms used in this discussion warrant definition. "Plain concrete" and "plain masonry" are not necessarily devoid of all reinforcing; however, they have less reinforcing than is required to be officially designated as being "reinforced." "Unbalanced backfill" is defined as the difference in height between the exterior and interior finish ground levels except that, when an interior concrete slab floor is present, the height is measured from the top of the slab to the exterior finished ground level.

3.9 FOUNDATION WALL THICKNESS, HEIGHT, AND REQUIRED REINFORCING

The minimum thickness of plain concrete and plain clay or concrete masonry foundation walls ranges from 6 inches to 12 inches depending on several variables. These variables include:

- The height of the wall,
- The site's soil classification, and
- The height of any unbalanced backfill.

Foundation wall thickness also must be at least equal to the width of the supported wall.

For plain masonry foundation walls, the minimum thickness also is dependent on the use of solid masonry units or hollow units that can be either grouted or ungrouted. Generally, the minimum thicknesses for solid masonry and grouted hollow masonry are identical whereas the minimum thickness for ungrouted hollow masonry is greater. Minimum wall thickness for plain concrete and plain masonry walls, based on specific combinations of these variables, are listed in *IRC* Table R404.1.1(1).

For SDCs D₁ and D₂, *IRC* Section R404.1.4 imposes the following additional limitations on plain concrete and plain masonry foundation walls that are not specified in *IRC* Table R404.1.1(1):

- Wall height is limited to 8 feet.
- Unbalanced fill height is limited to 4 feet.
- A single horizontal No. 4 reinforcing bar shall occur in the upper 12 inches of the wall.
- Plain masonry walls shall be a minimum of 8 inches thick.
- Plain concrete walls shall be a minimum of 7.5 inches thick except that a 6-inch minimum thickness is permitted when the wall height does not exceed 4 feet 6 inches.
- Vertical reinforcing of masonry stem walls shall be tied to horizontal reinforcement located in the footing.

In SDCs D₁ and D₂, when the foundation exceeds 8 feet in height or supports more than 4 feet of unbalanced fill, additional minimum reinforcing requirements apply. First, two No. 4 horizontal reinforcing bars are required at the top of the wall rather than just one. In addition, a concrete or masonry wall's vertical reinforcing is required to meet additional prescriptive minimums. The vertical reinforcing size and maximum spacing are dependent on wall thickness, wall height, unbalanced fill height, and soil classification. Three *IRC* Tables — Tables R404.1.1(2), (3) and (4) — specify the minimum vertical reinforcing based on specific combinations of these variables. The *IRC* also allows alternative sizes and spacing of reinforcing up to a maximum spacing of 6 feet; however, the alternate size and spacing must result in an equivalent cross-sectional area of reinforcing per lineal foot of wall as prescribed in the tables.

Above-code Recommendation: As described earlier, reinforcing should always be continuous; therefore, lap splices are needed where discontinuities occur in either horizontal or vertical reinforcing. Lap lengths should not be less than 24 inches for No. 4 bars or 30 inches for No. 5 bars.

Regardless of Seismic Design Category, all vertical reinforcing for these reinforced masonry or concrete foundation walls must be at least ASTM Grade 60 (yield strength of 60,000 psi). This is important to note because No. 4 bars are commonly available in Grade 40, which has a lower yield strength. In addition, the distance from the soil side face of the wall to the centerline of the vertical reinforcing must be 5 inches in an 8-inch-thick wall, 6.75 inches in a 10-inch-thick wall, and 8.5 inches in a 12-inch-thick wall.

3.10 WOOD-FRAMED WALL BOTTOM PLATE AND FOUNDATION SILL PLATE ANCHORAGE

For the purpose of the following discussion, the terms “wall bottom plate” and “foundation sill plate” are used to distinguish between two different locations of wood members along a foundation. A wall bottom (sole) plate either is directly supported by a slab-on-grade foundation as shown in Figure 3-5 or is part of a cripple wall supported directly on a foundation when a slab on grade does not occur. A foundation sill plate is different in that it occurs without wall studs

framing on top of it; instead, a foundation sill plate is the bearing support between floor joists or floor beams and the foundation as shown in Figure 3-6.

In all Seismic Design Categories, where anchor bolts are required to connect a bottom plate or foundation sill plate to a foundation, the bolts must have a minimum embedment of 7 inches into a concrete or masonry foundation, and they must have a nut and washer tightened on each bolt. Typically, anchor bolts must be a minimum of 1/2-inch diameter and be spaced not to exceed 6 feet on center. However, in SDCs D₁ and D₂, the maximum bolt spacing is limited to 4 feet for buildings with more than two stories. Because the *IRC* prescribes bracing only for houses in SDC D₂ up to a maximum of two stories, the closer spacing is actually only applicable in SDC D₁ where three stories is permitted. This decreased bolt spacing provides 50 percent more shear capacity at the sill-plate connection in recognition that earthquake loads generated in a three-story building will be greater than those in a one- or two-story building.

Some builders may choose to use 5/8-inch diameter bolts at the standard 6 feet on center spacing in place of using 1/2-inch diameter bolts at a required 4 feet on center spacing. Based on bolt capacities listed in 2001 NDS Table 11-E, for most species of wood, 5/8-inch bolts at 6 feet on center spacing provide approximately 95 percent of the capacity of 1/2-inch bolts at 4 feet on center spacing. However, the approval of local officials should always be obtained prior to making any such substitution.

In SDCs D₁ and D₂, the washer to be installed under the anchor bolt nut must be a 3-inch by 3-inch square plate with a minimum thickness of 1/4 inch. This increased washer size limits the potential for splitting of bottom plates.

Above-code Recommendation: Splitting of sill plates can occur when the ends of braced wall segments are lifted vertically during the rocking motion braced walls undergo while resisting earthquake loads. Cyclic testing of shear walls has shown that a standard round cut washer is too small to provide any appreciable resistance to this uplift and allows sill plates to split but, when larger square washers are used, walls can sustain much higher lateral loads before sill plate splitting will occur. **For this reason, the use of plate washers is also recommended on anchor bolts connecting to the foundation in SDC C.**

3.11 REQUIRED LOCATIONS FOR ANCHOR BOLTS ALONG EXTERIOR WALLS

Independent of Seismic Design Category, anchor bolts are required to connect a wall bottom (sole) plate or foundation sill plate to foundations located along all exterior wall lines. A minimum of two anchor bolts are required in each individual length of plate, with one bolt located not more than 12 inches nor less than 7 bolt diameters from each end.

3.12 REQUIRED ANCHORAGE ALONG INTERIOR BRACED WALLS

The anchorage of wall bottom plates along interior wall lines is a bit more complex than it is for exterior walls. The general rule is that when interior braced walls are supported directly on a

continuous foundation, the bottom plate of the wall must be anchored using the same bolting pattern as required for exterior walls. However, the *IRC* currently requires a continuous foundation along interior braced wall lines in only a few situations. Consequently, bolting of the sole plate of an interior braced wall to a foundation occurs only rarely because a foundation is not normally required.

When an interior braced wall frames onto a raised wood framed floor, the code is clear that the anchorage connection of the braced wall sole plate uses nails. However, the *IRC* is silent regarding exactly what kind of anchorage is required for connecting an interior braced wall to a slab-on-grade when a continuous foundation is not required and not provided. One common example is a slab-on-grade house that has its exterior walls less than 50 feet apart and therefore does not require its interior braced walls be supported on a continuous foundation. In such a case, the slab usually will not have the thickness necessary to allow installation of anchor bolts with the standard 7 inches of embedment. However, it is reasonable to assume that the braced wall bottom-plate-to-slab connection should provide lateral load resistance at least equivalent to the typical anchorage to a foundation using bolts. For the 1/2-inch diameter bolts at 6 feet on center, the bolt shear capacity from NDS Table 11E, adjusted by 1.6 for earthquake loads, ranges from 152 plf in Spruce-Pine-Fir lumber, to 176 plf in Southern Pine lumber. Therefore, the connection to be provided to the slab should provide at least the same capacity as the 1/2-inch anchor bolts. For 5/8-inch bolts at 6 feet on center, the capacity ranges from 219 plf in Spruce-Pine Fir to 248 plf in Southern Pine.

When anchor bolts cannot be used because of limited slab-on-grade thickness, interior wall bottom plates often are connected to a slab-on-grade with powder-driven nails or pins as shown in Figure 3-14. However, because of their small diameter and shallow embedment length into the slab, each powder-driven nail or pin has significantly less lateral capacity than a single 1/2-inch diameter bolt. The nails or pins would need to be spaced at a much closer center-to-center spacing to be equivalent to a 1/2-inch diameter bolt at 6 feet on center. The actual spacing needed to achieve equivalence with anchor bolts generally depends on the diameter and length of the nail or pin.

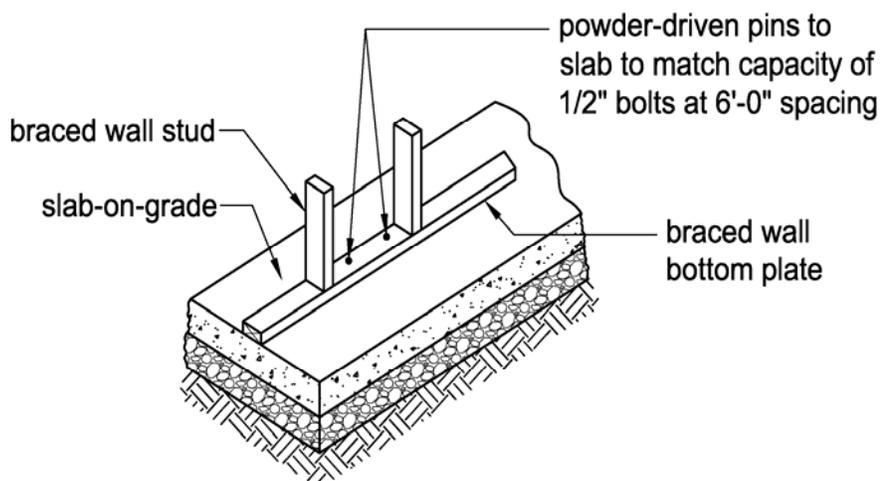


Figure 3-14 Interior braced wall on slab-on-grade.

Many manufacturers of powder-driven nails or pins have published shear and tension capacity values for their specific products when connecting wood members to concrete. However, it should be noted that powder-driven nails or pins used for this purpose generally have very little embedment depth into the concrete and, as a result, have very little tension capacity to resist the uplift that can occur at the ends of braced walls. Because of this limited tension capacity, they may not perform nearly as well as bolts. In addition, when pins are used, there is no way to install the square plate washers required on anchor bolts in SDCs D_1 and D_2 and recommended for use in SDC C.

Above-code Recommendation: In SDCs C, D_1 and D_2 , when interior braced walls use wood structural panel sheathing, it is recommended that bottom plates be anchored to a thickened slab-on-grade using bolts as shown in Figure 3-5. Instead of the 18-inch thickness shown in Figure 3-5, only a minimum 10-inch thickness is necessary for the slab-on-grade to allow for 7-inch minimum embedment of the bolt and 3 inches of additional clearance from the end of the bolt to the bottom of the thickened slab.

3.13 ANCHORING OF INTERIOR BRACED WALLS IN SDCs D_1 AND D_2

In SDCs D_1 and D_2 , anchor bolts are required for interior first-story walls when:

- The first-story interior wall is a bearing wall (which may or may not be a braced wall line) and it is supported on a continuous foundation.
- The interior first story-wall is a braced wall line and that wall line is required to be supported on a continuous foundation.

When applying the two rules listed above, one must differentiate between interior walls that are bearing walls and those that are braced walls. Although interior bearing walls can be braced walls, this is not always the case. Therefore, to apply the rules it must be determined that:

- An interior wall is only a bearing wall and *not* a braced wall,
- An interior wall is a braced wall but is *not* a bearing wall, or
- The interior wall is *both* a bearing wall and braced wall.

Summaries of the 2003 *IRC* minimum requirements for continuous foundations and for installing anchor bolts to a foundation along braced wall lines and bearing walls are presented in Tables 3-1 and 3-2, respectively. When an interior wall is both a bearing wall and a braced wall, the most restrictive requirement from Tables 3-1 and 3-2 applies.

Table 3-1 Summary of 2003 IRC Continuous Foundation and Anchor Bolt Requirements for Braced Wall Lines in One- and Two-family Houses

Seismic Design Category	Continuous Foundation Required At Braced Wall Lines	Anchor Bolts Required	Anchor Bolt	
			Diameter	Spacing
A, B and C	YES along Exterior Braced Walls	YES	½" @	6'-0"
A, B and C	NO along Interior Braced Walls	NO	N/A	
D ₁	YES along Exterior Braced Walls	YES ¹	½" @	6'-0" ½" @ 4'-0" >2 story
D ₁	NO along Interior Braced Walls Unless wall lines spaced > 50 feet	NO	N/A	
D ₂	YES along Exterior Braced Walls	YES ¹	½" @	6'-0" ³
D ₂	NO along Interior Braced Walls of 1 Story unless spaced > 50 feet	NO	N/A	
D ₂	YES along Interior Braced Walls of Two-Story ²	YES ^{1,2}	½" @	6'-0" ³

¹ Requires a square plate washer 3 x 3 x ¼ inch on each bolt.

² A continuous foundation is NOT required for interior braced wall lines of a two story building in SDC-D₂, provided that all of the following conditions are met: A) The spacing between continuous foundations does not exceed 50 feet, B) cripple walls (if provided) do not exceed 4 feet in height, C) first story braced walls are supported on beams double joists or blocking, and D) braced wall line spacing does not exceed twice the building width measured parallel to the braced wall line.

³ Buildings are limited to two-story in SDC D₂, therefore anchor bolts at 4'-0" on center spacing do not apply.

Table 3-2 Summary of 2003 IRC Continuous Foundation and Anchor Bolt Requirements for Bearing Walls in One- and Two-family Houses

Seismic Design Category	Continuous Foundation Required At Bearing Walls	Anchor Bolts Required	Anchor Bolt	
			Diameter	Spacing
A, B and C	YES along Exterior Walls	YES	½" @	6'-0"
A, B and C	NO along Interior Bearing Walls	NO	N/A	
D ₁	YES along Exterior Walls	YES ¹	½" @	6'-0" ½" @ 4'-0" >2 story
D ₁	YES along Interior Bearing Walls supported on a slab-on-grade	YES ¹	½" @	6'-0" ½" @ 4'-0" >2 story
D ₁	NO along Interior Bearing Walls supported on a raised floor	NO	N/A	
D ₂	YES along Exterior Walls	YES ¹	½" @	6'-0" ²
D ₂	YES along Interior Bearing Walls supported on a slab-on-grade	YES ¹	N/A	
D ₂	NO along Interior Bearing Walls supported on a raised floor	NO	N/A	

¹ Requires a square plate washer 3" x 3" x ¼" on each bolt.

² Buildings are limited to two-story in SDC D₂, therefore anchor bolts at 4'-0" on center spacing do not apply.