# Chapter 4
# FLOOR CONSTRUCTION

Woodframe floor systems and concrete slab-on-grade floors are discussed in this chapter. Although cold-formed steel framing for floor systems also is permitted by the *IRC*, it is not covered here; rather, the reader is referred to the AISI *Standard for Cold-Formed Steel Framing – Prescriptive Method for One- and Two-Family Dwellings* (AISI, 2001) for guidance. Also permitted but not discussed here are pressure-treated wood floor systems on ground; information on the use of these systems is provided in *IRC* Chapter 5.

## 4.1 GENERAL FLOOR CONSTRUCTION REQUIREMENTS

Woodframe floor systems form a horizontal diaphragm at each level where they occur and transfer earthquake lateral loads to braced walls below that floor level or directly to the foundation when the lowest floor is supported on a foundation. When a floor supports walls above and is supported on walls below as shown in Figure 4-1, the lateral loads in the floor system are based on the mass of the floor itself and a portion of the mass of all the walls in the stories immediately above and below the floor. (See Chapter 2 of this guide for a discussion of the complete load path.)

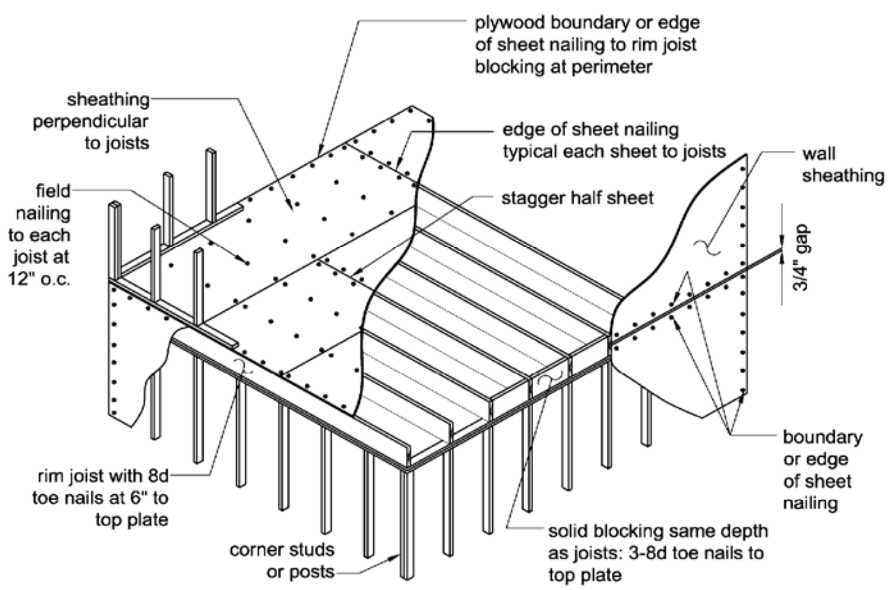


**Figure 4-1 An unblocked floor diaphragm.**

Concrete slab-on-grade floors typically are constructed with a concrete perimeter foundation and together these elements form the base of the building. Lateral forces from exterior and interior braced wall lines are transferred to a slab-on-grade via connections between the bottom plate of a braced wall and the slab. In turn, the concrete slab and foundation transfer those forces directly to the ground as shown in Figure 4-2. (For more information on anchorage of braced walls to slab-on-grade construction, see Chapter 3 of this guide.)

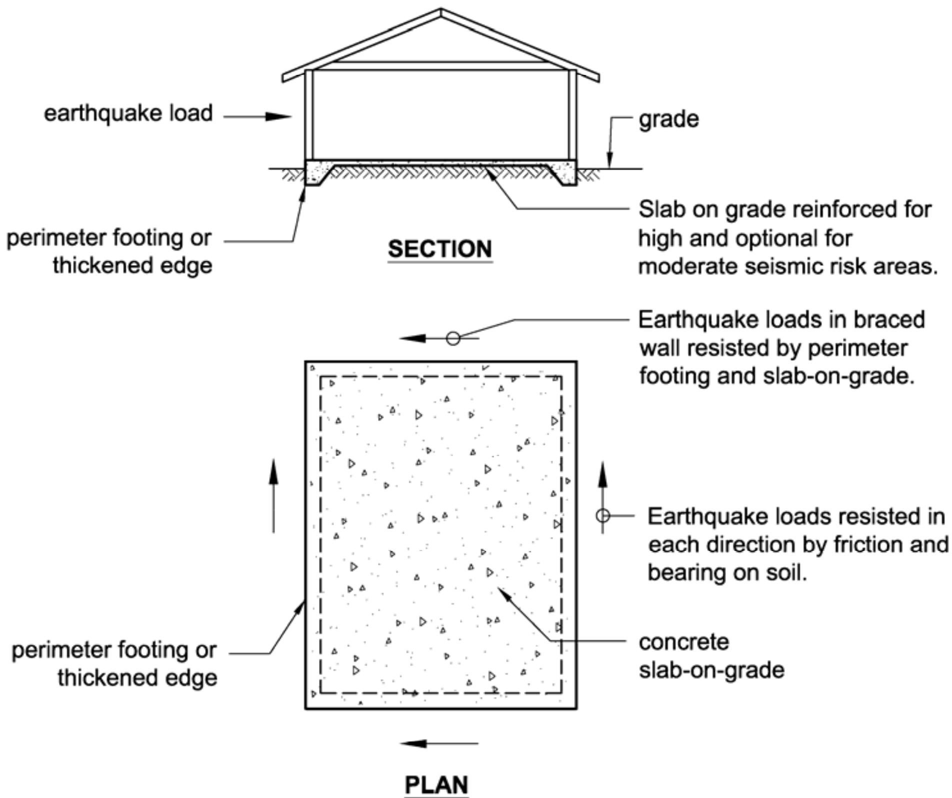


**Figure 4-2 Slab-on-grade and perimeter footing transfer loads into soil.**

## 4.2 WOODFRAME FLOOR SYSTEMS

Woodframe floors typically consist of repetitive joists or trusses, at a prescribed spacing, sheathed with either boards or wood structural panels attached to the top surface. Finish materials such as gypsum board typically are applied to the bottom surface where it serves as the ceiling for a room below. Blocking between joists or trusses is used at the ends of the floor joists or trusses (or a continuous band joist can be used at the ends) and where walls occur above or below. Floor systems also include beams, girders, or headers where needed to support joists. Joists can be sawn lumber, end jointed lumber, or a variety of prefabricated (engineered) members. Examples of engineered lumber include wood I-joists, trusses, and solid rectangular structural composite members such as parallel strand lumber (PSL), laminated veneer lumber (LVL), and laminated strand lumber (LSL). Beams, girders, or headers and blocking also can be either sawn lumber or engineered lumber.

The primary design consideration in choosing the minimum size and the maximum span and spacing of floor joists, trusses, beams, girders, and headers is adequate support for dead and live vertical loads as prescribed by the code depending on the uses that a floor must support. Vertical deflection of a floor is another design consideration that can limit the maximum span of floor members. Tables in *IRC* Chapter 5 and similar tables in other documents such as those published by the American Forest and Paper Association (AF&PA) or engineered lumber manufacturers are available for use in selecting the proper combination of minimum size and maximum span and spacing of floor framing members.

## 4.3 CANTILEVERED FLOORS

When floor joists cantilever beyond a support, joist size and spacing are limited by prescriptive tables in *IRC* Chapter 5. *IRC* Table R502.3.3(1) addresses support of a roof and one story of wall for roof spans up to 40 feet and snow loads up to 70 psf. *IRC* Table R502.3.3(2) addresses cantilever joists supporting an exterior balcony. When a floor is supporting more than a roof and one story of wall, the maximum prescriptive cantilever distance is limited by the *IRC* to the depth of the joist. If longer cantilevers are desired, a registered design professional must design that portion of the floor system.

In Seismic Design Categories $D_1$ and $D_2$, when cantilevered floor joists support braced wall panels in the story above, the cantilevered floor is limited by several additional prescriptive requirements in *IRC* Chapter 3. This is because the braced wall above and braced wall below are offset out-of-plane. When a floor cantilever supporting a braced wall does not meet the *IRC* limits, that portion of the house is defined as having an irregularity that prevents the use of prescriptive wall bracing where the irregularity occurs. In such a case, engineering must be applied to resolve the out-of-plane offset of the braced walls located in the stories above and below that floor. The maximum permitted cantilever of a second floor supporting a braced wall and roof is illustrated in Figure 4-3. (Also see the discussion of load path in Chapter 2 of this guide.)

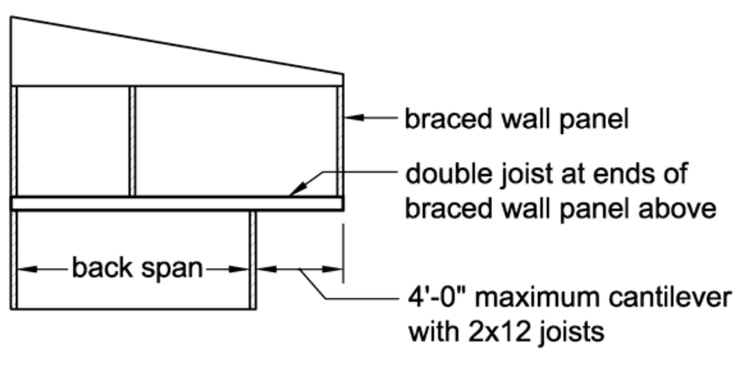


**Figure 4-3 Cantilevered floor restrictions.**

The specific limits and requirements in *IRC* Chapter 3 for cantilevered floors in SDCs $D_1$ and $D_2$ that support braced walls are not particularly difficult to meet and appear to omit addressing the uplift restraint that may be necessary at the back span support of cantilever joists. In SDCs $D_1$ and $D_2$, cantilever floor joists supporting a braced wall panel may not extend more than four times the nominal depth of the joist when the following set of rules is met:

- Joists must be 2x10 nominal or larger at 16-inch maximum spacing.
- The back span of the cantilever joist must be at least twice the cantilever distance.
- Joists must be doubled at the ends of the braced wall panel above.
- A continuous rim joist is connected to the end of each cantilevered joist. If that rim joist is spliced along its length, the splice must be made with either: (a) a 16-gage strap having 6 – 16d common nails on each side of the splice or (b) by using wood blocking having the same size as the rim joist, installed between the cantilevered joists, and nailed to the rim with 8 –16d common nails on each side of the splice.
- The cantilever end of the joist is limited to supporting uniform loads from a roof and wall above and, if supporting a header above, the header span is limited to 8 feet.

These rules are illustrated in the framing plan shown in Figure 4-4. What is not mentioned in this list of rules is the need for connections to resist uplift at the back-span (interior) end of a cantilever joist as noted in Figure 4-4. In *IRC* Table R502.3.3(1) for cantilever joists supporting a roof and wall, the uplift is determined using a back-span distance that is three times the cantilever distance (3:1). Because the minimum back span specified in the *IRC* Chapter 3 (see Item 2 above) is only twice the cantilever distance (2:1), the uplift values in *IRC* Table R502.3.3(1) would need to be increased by a factor of 1.5 just to address the gravity loads.

When the downward earthquake overturning load from the ends of a braced wall panel supported by cantilever joists are considered in addition to gravity loads, the uplift load at the back-span end of the joist obviously will increase. Therefore, depending on the actual back-span-to-cantilever-length ratio, the back-span end of the double cantilever joists supporting the ends of a braced wall may need to provide uplift restraint as much as twice than that listed in *IRC* Table R502.3.3(1). However, because the magnitude of the uplift load at the back-span end of a cantilevered joist reduces as the back-span length increases, it is possible that a cantilever joist that is continuous over its interior support will result in zero uplift at the back-span end. When cantilever joists are continuous over an interior support, the back span increases and the uplift at the end of the joist is greatly reduced. Therefore, the specific cantilever floor joist layout and ratio of the length of the back span to the cantilever will determine if and how much uplift may need to be resisted.

**Above-code Recommendation: In SDCs C, $D_1$ and $D_2$, when a braced wall is supported at the ends of cantilever joists, the back-span uplift connection capacity should be determined using engineering principals for the specific back-span and cantilever distances involved.**

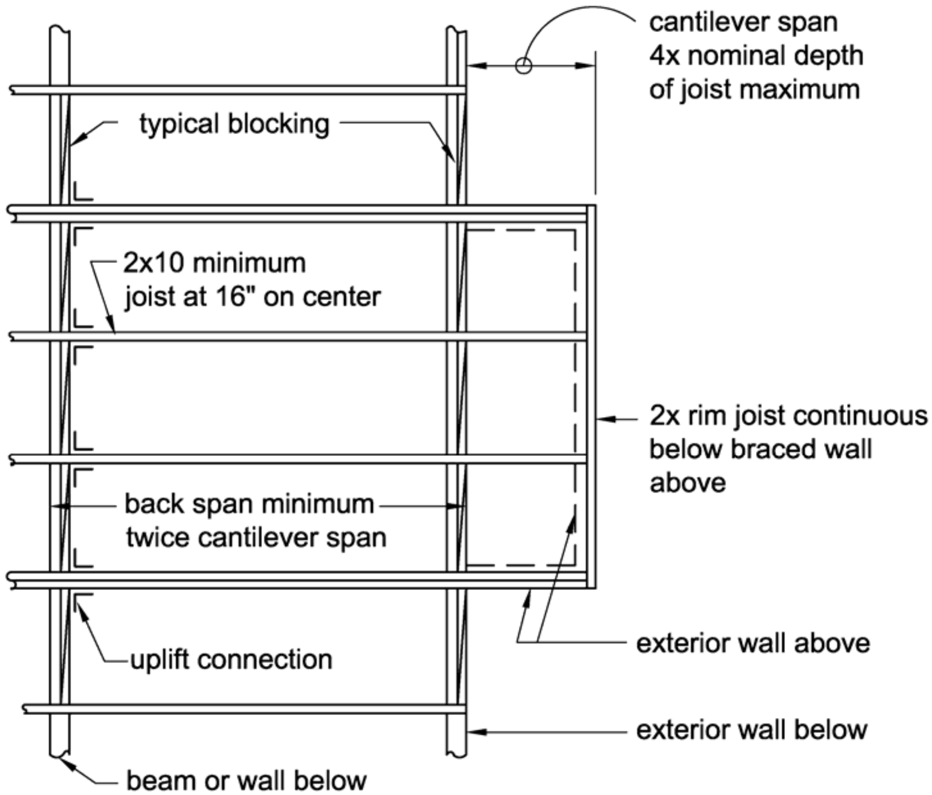


**Figure 4-4 Cantilever joist at braced wall above.**

## 4.4 REQUIREMENTS FOR BLOCKING

It is important in floor framing construction to prevent joists (or trusses) from rotating or displacing laterally from their intended vertical position. Rotation loads occur because, when floor sheathing is resisting lateral loads oriented perpendicular to the joist, those lateral loads are actually trying to move the top edge of the joist sideways.

Preventing rotation is often accomplished by installing full-depth solid blocking at the ends of joists. The ends of joists also can be restrained by attaching the joist to a continuous rim or band joist or a header or, in balloon framed walls, by attaching the joist to the side of a stud. In SDCs $D_1$ and $D_2$, additional solid blocking between joists (or trusses) is necessary at each intermediate support even when that location is not at the end of the joist. For example, intermediate support should be located at an interior girder or bearing wall where joists are continuous over that support. Blocking installed between joists supported by an interior floor girder is illustrated in Figure 4-5.

Blocking also is required below an interior braced wall line in all Seismic Design Categories when joists are perpendicular to the braced wall. Although the *IRC* is silent regarding minimum depth and width for these blocks, the intent of this added blocking is to provide a nailing surface for the 16d common nails used to connect the bottom plate of the braced wall to the floor. This nailing is an important part of the lateral load path; therefore, the blocking should be of a depth sufficient to allow full embedment of the 16d common nails and of sufficient width to prevent the nails from missing the block.

Assuming floor sheathing is at least 1/2- inch thick, the minimum depth of the blocking should be 1-1/2 inches. Therefore, a flat 2-inch by 4-inch block as shown in Figure 4-6 can provide sufficient depth and, when accurately placed below a wall, can provide a width that greatly reduces the potential for bottom plate nails missing the block.

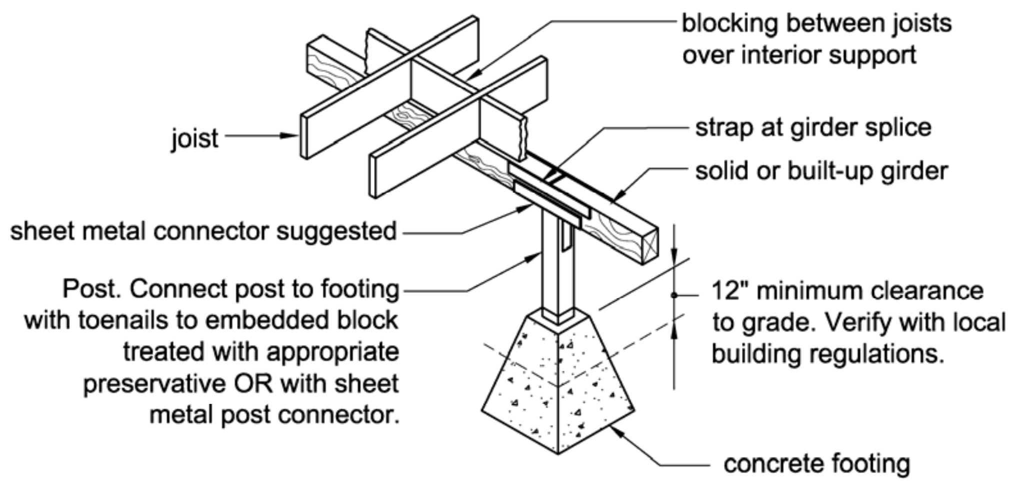


**Figure 4-5 Interior bearing line.**

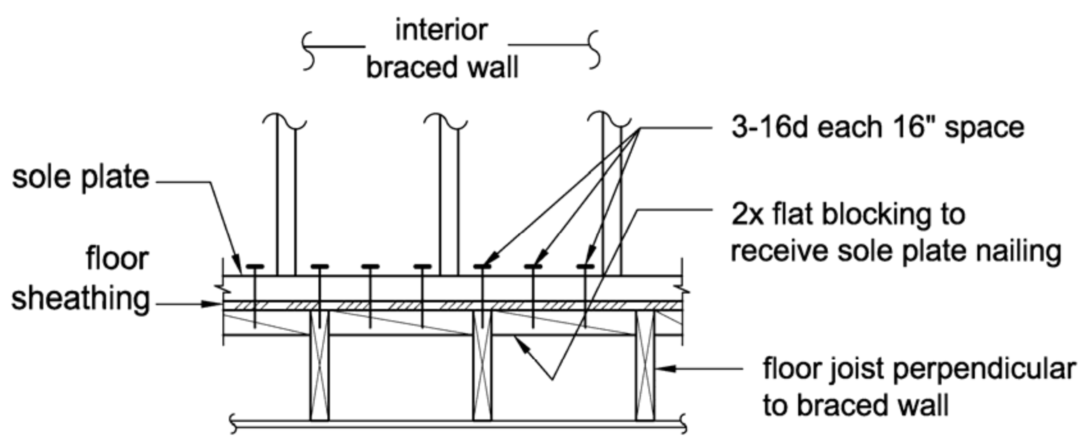


**Figure 4-6 Blocking below interior braced wall where floor joists are perpendicular to wall.**

When an interior braced wall also is a bearing wall and joists below the wall are parallel to the wall, a double joist or a beam typically is provided in the floor below the wall. Occasionally this pair of joists may be spaced apart to allow for piping or vents passing vertically from the wall above through the floor. When this occurs, the double joists cannot be located directly below the wall's bottom plate. To provide a nailing surface for the bottom-plate connection of the braced wall above, 2x flat blocking should be installed in line with the braced wall's bottom plate between and parallel to these spaced joists as shown in Figure 4-7.

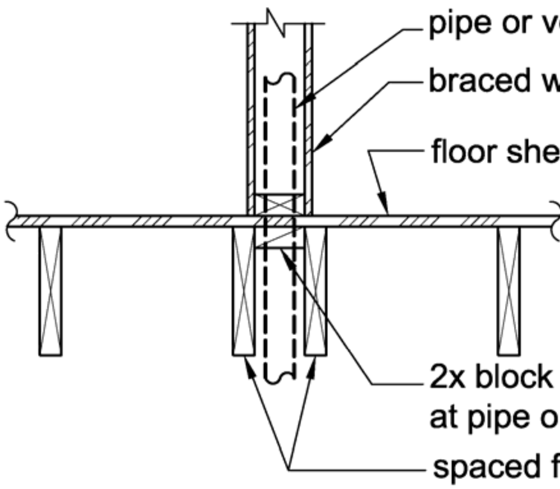


**Figure 4-7 Blocking for floor joists spaced apart for piping in floor.**

## 4.5 CONNECTION OF FLOOR JOISTS TO WALL TOP PLATE OR FOUNDATION SILL PLATE BELOW

Floor joists (or trusses) are required to be connected to the top plate of supporting walls or to a foundation sill plate as specified in *IRC* Table R602.3(1). Each of these connections provides a load path to transfer loads from the floor diaphragm into the braced walls or the foundation below. Nailed connections must meet the following minimum requirements:

- Rim or band joists parallel to a wall or foundation require a toe-nailed connection to the wall top plate or foundation sill plate using 8d box or common nails at 6 inch spacing.

- Floor joists perpendicular to a wall top plate or foundation sill plate require a toe-nailed connection using three 8d box or common nails.

- When blocking is installed between the floor joists, the blocking requires a toe-nailed connection to the wall top plate or foundation sill plate using a minimum of three 8d box or common nails in each block.

Where toe nailing is used, it must be done correctly so that it can transfer the intended loads and so that the nails do not split the wood when being installed. Toe-nailed connections prescribed by the *IRC* should be acceptable when connecting joists to wall top plates or foundation sills that are perpendicular to the joists because these connections are not highly loaded by lateral loads. The primary lateral load transfer in a floor system occurs through the rim or band joists and through blocking that is parallel to braced walls or foundation sill plates.

Information on proper toe-nail installation is presented in Figure 4-8; however, that idealized picture of nail inclination and location is difficult to achieve in actual construction. Consequently, many toe-nailed connections that must transfer lateral loads may not actually perform very well.

**Above-code Recommendation: In SDCs C, $D_1$ and $D_2$, connections between joists or blocking and wall top plates or foundation sill plates that are parallel to the joist or blocking should use commercially available light-gage steel angles and nails of the correct diameter and length for the product.** Many of the toe-nailed connections specified in the *IRC* also can be made using light-gage steel angles through which face nails are driven into the two wood framing members being connected. Although light-gage angles may require more time to install than toe nails, the angle connections should reduce splitting of the wood and can provide a more reliable connection capacity for lateral loads compared to toe nails.

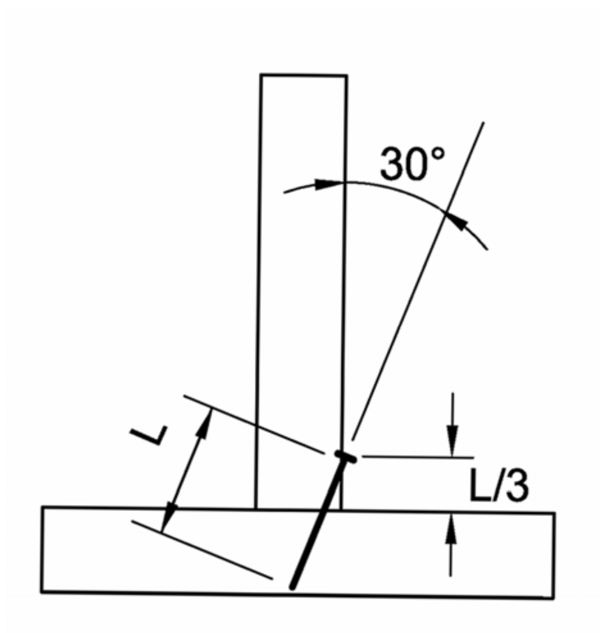


**Figure 4-8. Toe nail configuration requirements.**

## 4.6 FLOOR SHEATHING

Floor sheathing can be either wood boards installed perpendicular or diagonally to the joists or wood structural panels (as subfloor or combination subfloor-underlayment) installed with the long direction of the panel perpendicular to the joists. The minimum thickness for wood board sheathing depends on joist spacing and the orientation of the boards to the joist (e.g., perpendicular or diagonal). For wood structural panels, the minimum thickness is based on joist spacing and the grade of sheathing panels selected. *IRC* Chapter 5 contains tables to use in determining the required minimum thickness for sheathing materials based on a variety of joist spacings.

**Above-code Recommendation:** Wood boards are rarely used in modern house construction unless the underside of the floor is intended to be visible to the interior space below to achieve a specific architectural effect. **As an above-code measure, wood boards installed perpendicular to joists should not be used in SDC C, $D_1$, or $D_2$ unless wood structural panels are installed over the boards because the wood board sheathing alone provides little resistance to lateral loads**. In contrast, diagonally placed wood boards provide greater lateral capacity and should be acceptable for small rectangular-shaped floor areas.

For modern construction, floor sheathing typically will be wood structural panels (OSB or plywood). These panels are fastened to the joists based on a schedule prescribed in tables in *IRC* Chapter 6.

## 4.7 LATERAL CAPACITY ISSUES FOR WOOD FRAMED FLOORS USING WOOD STRUCTURAL PANELS

The lateral capacity of a floor diaphragm sheathed with wood structural panels is based on five factors:

- Sheathing thickness,
- Sheathing fastener type and size,
- Fastener spacing along supported sheathing edges,
- Presence or absence of blocking along all edges of each piece of sheathing, and
- Layout of the sheathing joints with respect to direction of lateral loading.

Below is a discussion of how differences in lateral capacity can result depending on how each of these is applied to the construction of a floor.

Sheathing thickness usually is selected based on the spacing of joists and, for floors, will never be less than 7/16 inch but normally is at least 5/8 inch. Generally, thicker sheathing will provide a more comfortable floor for the occupants to walk on and will have a greater lateral capacity compared to thinner sheathing using the same fastener size and spacing.

The most common sheathing fasteners used are nails with a minimum size of 6d common (0.113 inch x 2 inches) for a floor sheathing thickness of up to 1/2 inch. The minimum fastener size increases with increasing sheathing thickness to a minimum of 10d common nails (0.148 inch x 3 inches) for sheathing that is 1-1/8 inches thick. Larger diameter nails will provide greater lateral capacity than smaller nails in the same thickness of sheathing because the lateral capacity of a nail is directly proportional to its diameter. Therefore, using box nails or gun nails that have a smaller diameter than common nails will reduce the lateral capacity of a floor diaphragm.

Staples also can be used to fasten sheathing to framing members. Although not commonly used, *IRC* Table R602.3 (2) has information for specifying alternative sheathing fasteners including staples. Generally, staples of either 15 or 16 gage can be used in place of most nails at the same spacing as those nails. However, when using staples, it is important to understand that they must be installed with the crown parallel to the framing member below the sheathing edge being fastened.

Fastener spacing for floor sheathing is typically 6 inches along continuously supported panel edges and 12 inches along supporting members not located at panel edges. Greater lateral capacity can be obtained when fastener spacing along supported edges is reduced from 6 inches to 4 or 3 inches.

The *IRC* only requires floor diaphragms to be fastened along continuously supported panel edges. This includes where panel edges are located parallel to and over a joist and at the floor framing members forming the perimeter of the floor. The unsupported panel edges that are spanning perpendicular to the joists only need to be fastened at each joist. In engineering terms, this is called an unblocked diaphragm. See Figure 4-1 for the sheathing layout and nailing pattern for a portion of an unblocked diaphragm.

In contrast, a fully blocked floor diaphragm means that all edges of each sheathing panel that are not located on a joist are supported on and fastened to blocking. A blocked diaphragm will have significantly greater lateral capacity than an unblocked diaphragm having the same thickness of sheathing and attached with identical fasteners because the extra fasteners along the blocked edges provide additional capacity. Figure 4-9 shows the layout of sheathing and nailing of a portion of a blocked floor diaphragm. Fastening the sheathing to joists or blocking along all panel edges allows the shear loads being carried in the sheathing to be transferred from one panel to the next much more effectively. This, in turn, ties the floor together better and allows the braced walls below that floor to resist an earthquake more as a system than as individual walls.

**Above-code Recommendation:** The *IRC* requires that wood structural panel sheathing be installed with the long dimension of the panel perpendicular to joists, but it does not specify staggering of panel joints along the short direction of the panels. **Although not specifically required by the *IRC*, sheathing should be installed as shown in Figures 4-1 and 4-9 to achieve the greatest capacity**. This staggered sheathing layout pattern causes the individual sheathing panels to interlock and makes the whole floor act as a unit.

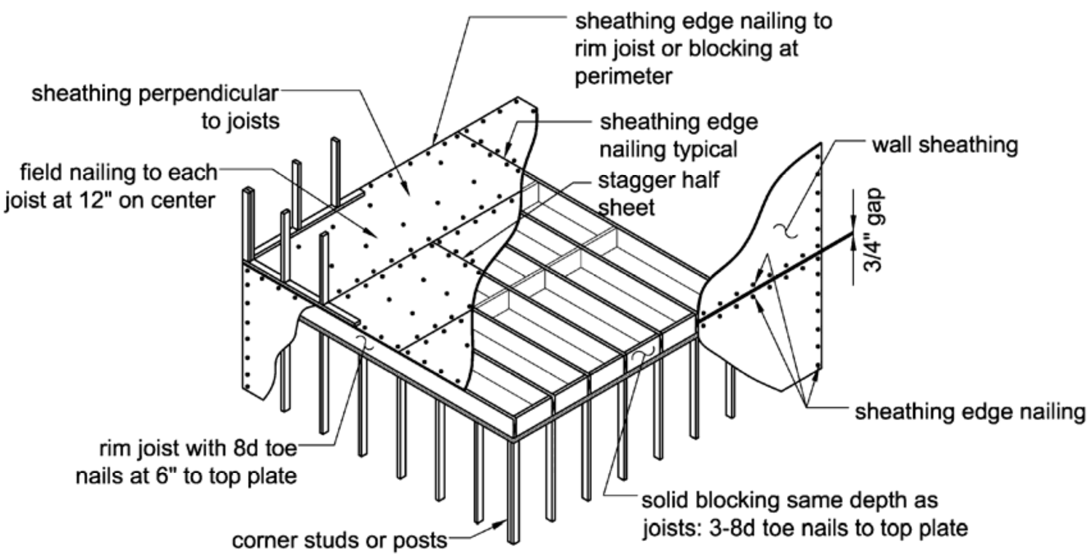


**Figure 4-9 Blocked diaphragm configuration.**

Lateral loads in a floor diaphragm also are affected by the distance between braced wall lines or between foundations located below the floor. The loads increase with increasing distance between lines of parallel braced walls or foundations. Therefore, a long and narrow floor diaphragm as shown in Figure 4-10 will have to transfer a greater load per foot along its short sides than along its long sides. In order to limit the maximum load along a short side, *IRC* Chapter 6 places limits on the maximum spacing between braced wall lines or foundations.

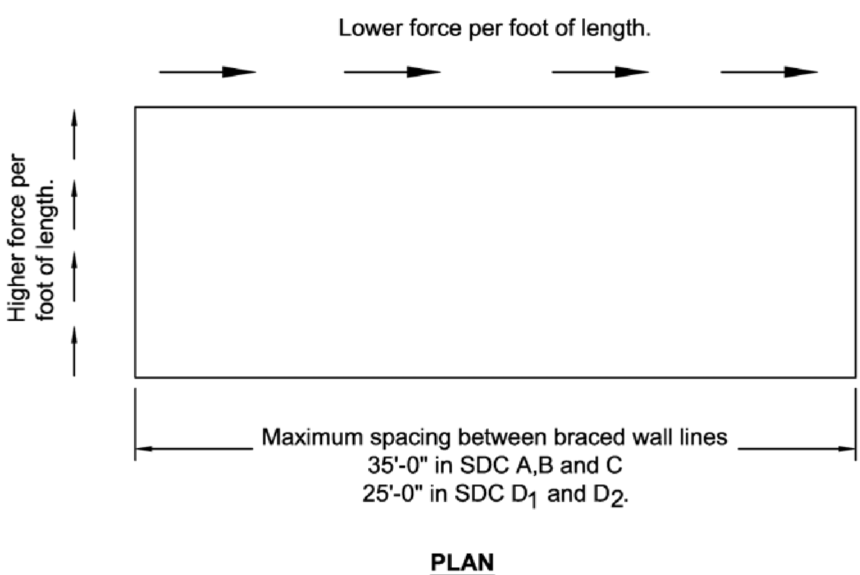


**Figure 4-10 Diaphragm loads on long and short sides.**

The size and location of floor openings such as for stairs or a two-story entry foyer can create concentrations of lateral loads in a floor diaphragm. To address this, *IRC* Chapter 3 limits openings through a floor or roof to the lesser of either 12 feet maximum or 50 percent of the least dimension of the floor. When openings exceed these limits, engineering of the floor or roof diaphragm is required.

**Above-code Recommendation: In SDCs C, $D_1$ and $D_2$, when floor openings exceed 50 percent of the *IRC* prescriptive opening size limits, it is recommended that 16-gage straps be installed along the edges perpendicular to the joists and extended beyond the opening by at elast 2 feet at each end as shown in Figure 4-11**. The straps can be nailed with 10d nails into the framing members forming the perimeter of the opening and into blocking beyond the corners. The straps and additional nailing act to reinforce the diaphragm and provide a dedicated path for lateral loads to be transferred around the opening to the portions of the floor beyond. Smaller openings such as those for chimneys or duct shafts do not require any special reinforcing.

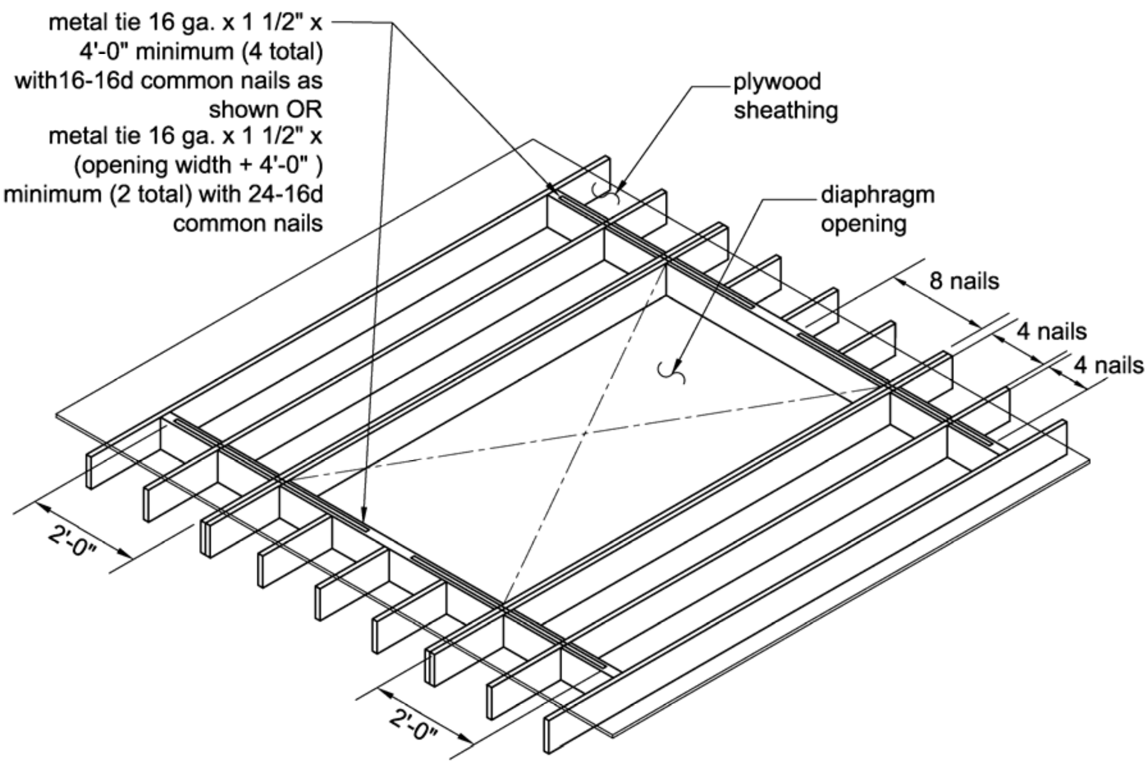


**Figure 4-11 Reinforcing straps at large diaphragm openings.**

## 4.8 CONCRETE SLAB-ON-GRADE FLOORS

A concrete slab-on-grade can be used as the base of a first-floor level or of a basement level. The minimum thickness for a concrete slab-on-grade is 3-1/2 inches except where expansive soil is present. Where expansive soils are encountered, a design for the slab-on-grade must conform to *IBC* Chapter 18 (see Chapter 3 of this guide for a discussion of the effects of expansive soil).

*Concrete Strength Requirements* – The minimum concrete compressive strength is 2,500 pounds per square inch (psi). Floor slabs having an exterior surface exposed to the weather in areas of moderate to severe concrete weathering must have higher compressive strength as specified in *IRC* Table R402.2. A map in *IRC* Chapter 3 identifies locations where moderate and severe weathering of concrete is expected to occur.

*Reinforcing of Concrete Slab-on-Grade Floors* – In the absence of expansive soils, the *IRC* does not require reinforcing of concrete slabs. Reinforcing typically is used to provide tension capacity in concrete and thereby reduce cracking caused by a variety of loads including temperature variations. Concrete alone has very good compression capacity but has a very low capacity for tension. Therefore, adding reinforcing bars to a slab-on-grade will provide much greater resistance to tension loads originating from earthquake loads and other soil conditions that could induce tension stress in the slab.

Reinforcing is required only where a slab-on-grade is thickened along its perimeter edge or below an interior bearing wall in SDCs $D_1$ and $D_2$. When exterior braced walls are spaced more than 50 feet apart, an interior braced wall also needs a foundation as part of the slab-on-grade in SDCs $D_1$ and $D_2$. (See Chapter 3 of this guide for information on where and how much reinforcing is needed in foundations provided with a slab-on-grade.)

**Above-code Recommendation:** When a slab-on-grade is placed separately from the perimeter footing below, the *IRC* does not specify any vertical reinforcing across this joint. When this condition occurs, the possibility of earthquake loads causing sliding along that joint is very real. **Therefore, as an above-code measure in SDCs C, $D_1$ and $D_2$, when the footing and the slab concrete are separately placed, it is recommended that vertical reinforcing dowels be placed across the joint between the slab and footing. These vertical dowels should be No. 4 steel reinforcing bars at 48-inch maximum spacing.** (More information on this subject is presented in Chapter 3 of this guide.)