

Chapter 6

ROOF-CEILING SYSTEMS

Woodframe roof-ceiling systems are the focus of this chapter. Cold-formed steel framing for a roof-ceiling system also is permitted by the *IRC* but will not be discussed; rather, the reader is referred to the *AISI Standard for Cold-Formed Steel Framing – Prescriptive Method for One- and Two-Family Dwellings* (2001) for guidance. Most of the recommendations for improving the earthquake performance of woodframe roof-ceiling systems also apply to cold-formed steel construction since the systems are very similar.

6.1 GENERAL ROOF-CEILING REQUIREMENTS

Woodframe roof-ceiling systems, regardless of the pitch of the roof, form a roof diaphragm that transfers earthquake lateral loads to braced walls in the story level immediately below the roof in the same manner that floors transfer loads from interior portions of the floor to the braced wall lines of the story below. The lateral loads in the roof-ceiling are based on the mass of the roof-ceiling assembly and a portion of the mass of the walls in the story immediately below the roof.

Woodframe roof-ceilings typically consist of repetitive rafters and ceiling joists or prefabricated (engineered) trusses at a prescribed spacing. They are sheathed with either spaced solid wood boards or with wood structural panels attached to the top surface of the rafter or truss. Figure 6-1 illustrates this type of roof and ceiling framing system. Roof members also can consist of repetitive beams spaced further apart than rafters, either with or without ceiling joists.

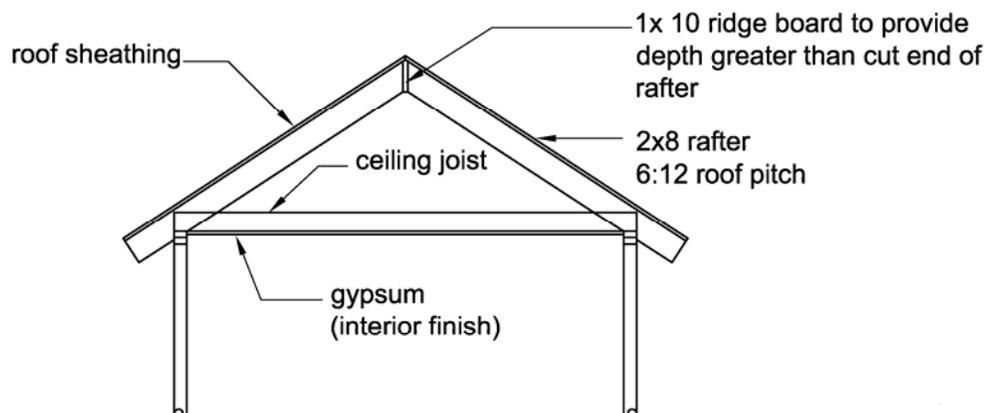


Figure 6-1 Typical light-frame roof-ceiling system.

Depending on the roof shape chosen for a house, hip and valley beam members may be needed where intersecting rafters change the direction of their span. Depending on the slope of the roof, hip and valley rafters can experience very high loads when supporting long-span rafters. Therefore, purlins are sometimes provided below and perpendicular to rafters. The purlins, in turn, are supported by a stud or post attached to a wall or beam below. Ridge boards also are often provided at the peak of a roof where sloping rafters meet. Blocking between rafters (or trusses) is used at the bearing points of rafters and ceiling joists to prevent lateral movement or rolling of the rafter. Finish materials such as gypsum board are typically applied to the bottom surface of ceiling joists or the bottom chord of a truss if the space below is to be occupied.

Rafters, purlins, ridge boards, and hip or valley members can be sawn lumber, end-jointed lumber, or any one of a variety of prefabricated (engineered) members. Examples of engineered lumber include wood I-joists or solid rectangular structural composite members such as parallel strand lumber (PSL), laminated veneer lumber (LVL), or laminated strand lumber (LSL). Roof beams and blocking can be either sawn lumber or engineered lumber.

The minimum required size and maximum span and spacing of roof rafters or beams, ceiling joists, and trusses is based on providing adequate support for dead and live vertical loads prescribed by the code. Snow loads must be considered for rafters, and attic storage must be taken into account for ceiling joists. Vertical deflection of rafters and ceiling joists is another design consideration that may limit the maximum span of these members. Rafter spans listed in prescriptive tables are based on the horizontal projection of the rafter rather than being measured along the slope, which would be a greater distance.

Tables in *IRC* Chapter 8 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 size, span, and spacing of most roof-ceiling framing members. Depending on the roof pitch, certain roof members require engineering to determine their size. For a roof pitch less than 3:12, the size of ridge boards and hip or valley members must be individually determined based on their spans and the span of the rafters they support.

6.2 SPECIAL FRAMING CONSIDERATIONS

Roof rafters must either be tied together at the ridge by a gusset plate or be framed to a ridge board. Ridge boards in roofs having a pitch of 3:12 or greater must be at least 1x nominal thickness and at least the same depth as the cut end of the intersecting rafters. Valley and hip members in a roof having a pitch of 3:12 or greater must be at least 2x nominal thickness and at least the same depth as the cut end of the rafters. Because the cut end depth of a rafter increases with increasing roof pitch, a 2x8 rafter will need a 1x10 nominal ridge board and a 2x10 nominal hip or valley member for a pitch up to 9:12. At a pitch exceeding 9:12, a 1x12 or 2x12 will be needed because the cut end of a 2x8 rafter will be greater than the 9-1/4 inch actual depth of a 1x10 or 2x10 nominal member. Figure 6-2 shows a 1x12 ridge board for a 12:12 pitch condition with the dimension for the cut end of a 2x8 rafter.

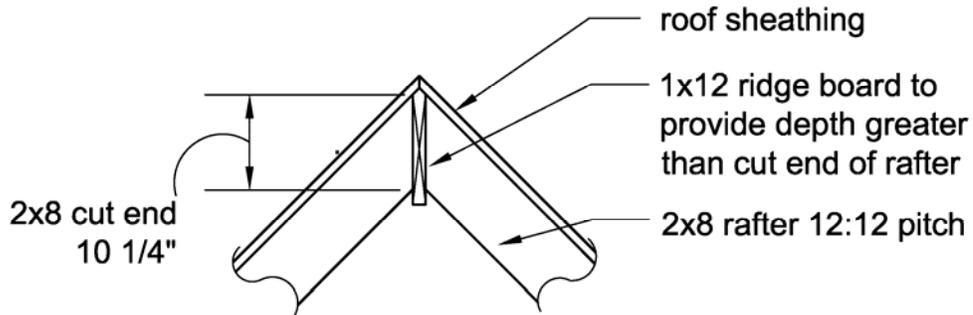


Figure 6-2 Ridge board for 12:12 pitch roof.

One additional consideration when using nominal 1x ridge boards is that ceiling joists or rafter ties are needed at the top plate of the supporting walls to prevent the walls from spreading outward. The ceiling joists or rafter ties act as a brace to resist the outward thrust of the rafters at the wall support ends of rafters. In the absence of ceiling joists or ties at the wall top plate, rafters must be supported at the ridge by a beam designed for the support of rafter loads. In addition, where a nominal 1x ridge is used and a 2x valley or hip member intersects the ridge, the valley or hip member must be supported by a stud or post attached to a bearing wall below to transfer the high loads associated with hip and valley rafters.

Above-code Recommendations: A special condition can occur at the gable ends of a roof. When the exterior wall at the gable end has its double top plate level with the low ends of the roof framing, the wall studs are not continuous to the roof sheathing along the gable edge. A section view of this condition is shown in Figure 6-3. **To provide above-code performance, the framing extending above the top plate to the level of the sloping gable end roof sheathing should be braced at regular intervals of not more than 4 feet on center at both the wall top plate level and along the top edge of the sloping roof edge.** This bracing permits the top of the exterior wall and the framing extending above to resist the lateral loads that are acting perpendicular to the wall. Without this bracing, the framing above the double top plate could be easily displaced because a hinge can form where the gable end wall framing attaches to the top plate.

Another above-code alternative to the framing shown in Figure 6-3 would be to provide wall studs that are continuous to a sloping double top plate located just below the roof sheathing (balloon framing). When continuous studs are provided, there is no weak location for a hinge to form. However, when this method is used, the required stud size, spacing, and maximum height must comply with *IRC* Table R602.3.1 or the wall studs will need to be engineered by a design professional. Bracing a gable end wall also is important for providing resistance to high winds, especially for roofs with a steep pitch.

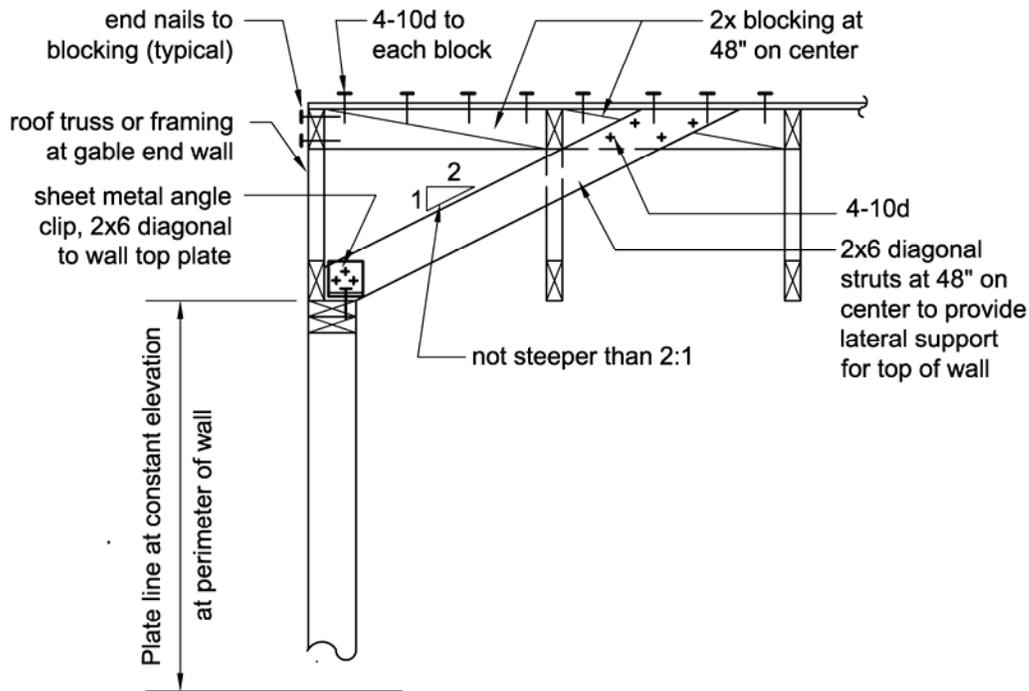


Figure 6-3 Gable end wall or gable truss bracing.

6.3 BLOCKING AND LATERAL LOAD PATHS FOR ROOF SYSTEMS

Rafters and ceiling joists having a nominal depth-to-thickness ratio exceeding 5:1 (e.g., 2x10) need blocking at their points of bearing to prevent them from rotating or displacing laterally from their intended position. Rotation loads on rafters occur when the roof sheathing is resisting lateral loads perpendicular to the rafter because these loads are actually trying to move the top edge of the rafter sideways. Preventing rotation is typically accomplished by installing full-depth solid blocking along wall top plates between rafters and ceiling joists. Figure 6-4 illustrates blocking installed between adjacent pairs of a ceiling joist and rafter that are bearing on an exterior wall.

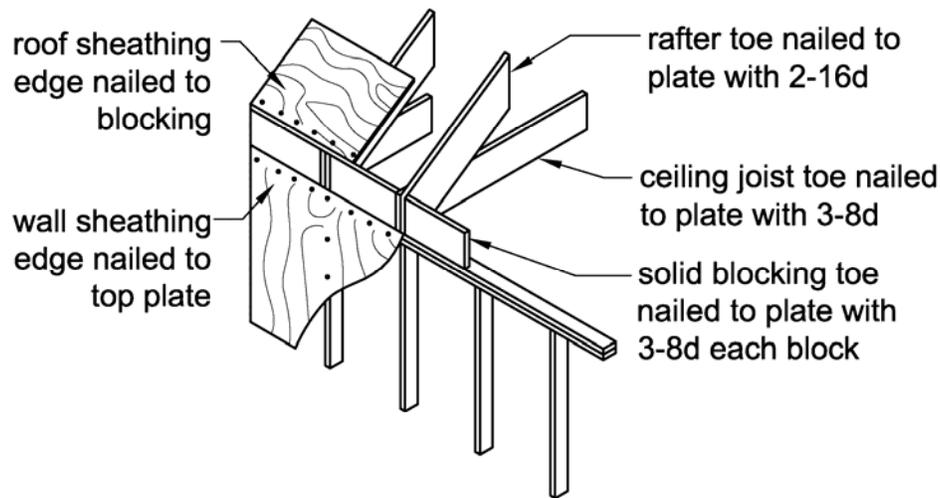


Figure 6-4 Blocking at rafters to exterior wall.

However, when the nominal size of a ceiling joist or rafter is 2x10 or smaller, blocking over the exterior wall may be omitted. This would be likely to occur where the roof overhang is enclosed by a soffit. Without an enclosed soffit, blocking is typically provided between rafters along the exterior wall line regardless of the rafter size to serve as a barrier between the outside and the attic space.

Because attics (or spaces between rafters where ceiling finish is attached to the bottom of the rafter) require ventilation openings, the spaces between rafters along exterior walls are typically used to provide some portion (if not all) of the required attic ventilation opening. When blocking is installed, ventilation openings often are provided by drilling holes in the blocking; when blocking is not required, ventilation can be provided through the entire opening space between rafters.

Although blocking may not be required for 2x10 and smaller rafters, there still must be a load path for lateral loads in the roof sheathing to reach the exterior braced walls immediately below the roof. The most direct load path is for the roof sheathing to be edge nailed to blocking between each rafter. That blocking is then nailed to the wall top plate with three 8d nails per rafter space as prescribed in *IRC* Table 602.3(1). This load path is shown in Figure 6-4. Although alternate load paths are certainly possible, the one shown is the most direct and is essentially the same load path the *IRC* provides between a floor and the braced walls below that floor.

Above-code Recommendation: In Seismic Design Categories D_1 and D_2 , blocking is recommended between rafters along exterior wall lines to provide a surface for the edge nailing of roof sheathing and to provide a very direct load path to the top plate of the exterior braced walls. When this blocking is provided, it also is necessary to ensure that minimum attic ventilation opening requirements are met. Depending on the attic area being ventilated, this can be accomplished by drilling holes in the blocking and, when more opening area is necessary, by adding gable end wall openings or ridge vents.

6.4 CONNECTION OF CEILING JOISTS AND RAFTERS TO WALLS BELOW

Ceiling joists and rafters (or trusses) are required to be connected to the top plate of supporting walls as specified in *IRC* Table R602.3(1). These connections also provide a portion of the load path that transfers loads from the roof diaphragm into the braced walls below. Ceiling joists require a toe-nailed connection to the top plate using three 8d box or common nails. Rafters also require a toe-nailed connection to the top plate using two 16d box or common nails. Blocking installed between the rafters or ceiling joists requires a toe-nailed connection to the top plate using a minimum of three 8d box or common nails in each block. Toe nailing must be done correctly if the needed transfer of loads is to occur; therefore, ensure that the nails do not split the wood. In high-wind areas, light-gage steel connectors often are used in place of these toe-nailed connections. The use of commercially available light gage steel connectors in place of toe nails can reduce wood splitting and provide more reliable load transfer. Additional information on proper toe-nailing installation is illustrated in Figure 4-8.

6.5 ROOF SHEATHING

Wood boards installed either perpendicular or at an angle to the rafters (or trusses) or wood structural panels can be used as roof sheathing. *IRC* Table R803.1 specifies the minimum thickness for wood board roof sheathing for various spacings between roof rafters, trusses, or beams.

Above-code Recommendation: Solid wood board roof sheathing is rarely used in modern housing construction except perhaps along roof eave overhangs. When wood boards are used and are installed perpendicular to rafters they provide a very weak diaphragm with little stiffness. **As a result, solid wood board sheathing installed perpendicular to rafters should not be used in Seismic Design Categories C, D_1 , and D_2 .** Wood boards installed diagonally would provide much better diaphragm capacity but are very rarely used in modern housing construction.

Wood structural panel roof sheathing is the most common roof sheathing used in current construction. The minimum thickness is based on rafter (or truss) spacing and the grade of sheathing panels selected. *IRC* Table R503.2.1.1(1) is used to determine the minimum required thickness for wood structural panel roof sheathing materials for a variety of rafter spacings. For roofs, the short direction panel joints between wood structural panels can be either staggered or

not staggered. Typical wood structural panel roof sheathing installation using staggered joints is illustrated in Figure 6-5.

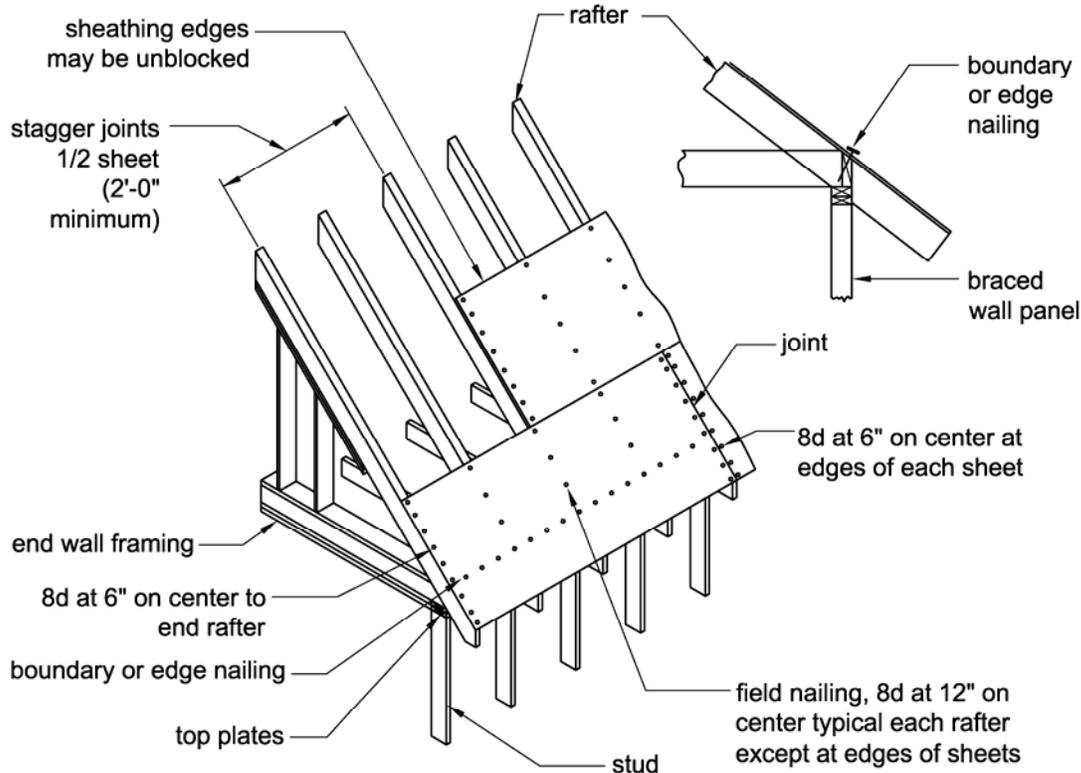


Figure 6-5 Typical roof diaphragm sheathing nailing when wood structural panels are used.

When the roof covering consists of wood shingles or shakes, *IRC* Chapter 9 permits the use of spaced wood boards as roof sheathing. However, spaced wood board sheathing is not permitted in Seismic Design Category D_2 . This limitation in SDC D_2 is intended to provide a stiffer and stronger roof diaphragm that will resist the larger lateral loads anticipated in SDC D_2 . When wood boards are used, they typically are nailed to each rafter with only two 8d box or common nails. Wood structural panel sheathing results in the stiffest roof diaphragms, and the panels typically are fastened to the rafters with 8d box or common nails spaced at 6 inches along supported edges and 12 inches in the field of the panel. When spaced wood boards are used, even fewer nails are provided than with solid wood board sheathing and even less lateral resistance results.

Above-code Recommendation: Spaced wood board sheathing is not recommended for use in Seismic Design Categories C and D_1 .

6.6 LATERAL CAPACITY ISSUES FOR WOOD FRAMED ROOFS

The lateral capacity of a roof diaphragm sheathed with wood structural panels is based upon the same five factors as floor diaphragms. (See the discussion in Section 4.7 of this guide for more information on the effects of sheathing thickness, fastener size and spacing, use of blocking, and layout of wood structural panel sheathing.)

The effects of distance between braced wall lines below the roof and the effects of large roof openings (e.g., skylights) are also similar to those discussed for floors. The recommendations for reinforcing floor diaphragms with large openings also apply when roof openings exceed the code maximum limits. (See Section 4-7 for more information.)

Although roof-ceiling systems typically are subjected to the smallest loads when a house experiences earthquake ground motion, several simple things can be done to improve the performance of the system.

Above-code Recommendations:

Reinforce the framing around skylights to provide positive connections to transfer the diaphragm loads around the opening. Strapping and blocking as illustrated in Figure 4-11 can be used to strengthen the roof around large openings and the additional cost for the blocking and strapping for a typical skylight opening would add less than 0.4 percent to the cost of the structural portion of the project.

Make sure all rafters and ceiling joists are blocked at all locations where they are in contact with a top plate of a wall below (alternately a rim joist may be used). For the exterior walls of the model house, this would cost 0.8 percent of the structural portion of the project. If interior walls were also blocked, an additional cost of 0.7 percent of the structural portion of the project would be incurred.

Glue the sheathing to the roof framing in the same way most floor sheathing is installed and then block the roof as well. Construction adhesives are typically used to prevent squeaky floors but they also strengthen and stiffen. The cost of adding adhesive to the roof system for the model house in this guide would be 1.8 percent of the structural system, and adding blocking to the roof system would add another 3.4 percent to the cost of the structural system.

6.7 QUALITY CONTROL

The most important item to monitor for quality of the roof diaphragm system is to ensure that the nails used to attach the sheathing to the framing are driven flush with the top of the sheathing and not overdriven and counter sunk into the sheathing materials. Overdriving sheathing nails has been shown to reduce the strength of shear walls and diaphragms. Evidence of a 40 to 60 percent loss in strength of the shear wall and diaphragm has been observed in laboratory tests of assemblies with overdriven nails. (See Section 5.1.4 of this Guide for more discussion on the effects of overdriven nails and how pneumatic tools can be altered to correct for this error.)

To ensure the quality of the roof-ceiling system, make sure blocking is installed correctly so that the wood framing is not split by the toe nailing.

If adhesives are used to attach the sheathing, attention needs to be paid to the time between the application of the adhesive and when the nails are driven to hold the sheathing in place. Especially in hot weather, the adhesive tends to skin over or cure on the surface quickly, which reduces the adhesion between the glue and the sheathing. Check the time allowed for each specific product used.

