

# Building Framing Systems and Best Practices

## 7.1 Introduction

**T**he importance of properly designed foundations was discussed in Chapter 6, *Coastal Foundations and Best Practices*. In this chapter, the importance of building framing systems is discussed.

A building's framing works in conjunction with its foundation to provide strength and stability for the structure; it is also another critical component of the load path. Properly designed and constructed building framing is important in all locations; however, in coastal areas (where wind, flood, and other loads can be extreme), ensuring proper building framing is critical.

Framing must transfer all gravity, uplift, and lateral loads to the foundation. In buildings (including residential structures), framing systems typically consist of the roof structure that supports the roof deck, exterior and interior load-bearing walls, beams, girders, posts, and floor framing. Shear walls (or steel moment frames in homes with large windows or other large openings) provide the strength to resist lateral loads.

The integrity of the overall building depends not only upon the strength of these components, but also on the adequacy of the connections that exist between them. Critical connections occur throughout the structure but, in most houses, the most critical connections exist where the roof system connects to supporting walls; at openings and headers in the walls; where walls connect to each other at floor levels; and where walls connect to the foundation. Refer to Chapter 5 for a detailed discussion on the continuous load path concept and the importance of connections within the load path.

While the term “framing” typically refers to either wood or light-gauge steel framing, walls constructed with concrete or masonry systems are also typically used to carry loads and to act as the frame of the building. Load-bearing wall systems of any construction type can and should be considered as part of building framing discussions. As such, load-bearing wall systems are presented in this chapter.

While buildings are constructed from the ground up, Chapter 5 identified how they are often analyzed from the roof down in order to track the presence of a continuous load path. Likewise, this discussion on building framing begins with the roof-framing structure. However, before concentrating on roof framing, a brief discussion of diaphragms and shear walls is presented because they are two of the key elements in the framing of load-bearing wall systems in most residential and light commercial construction.

## 7.2 Diaphragms and Shear Walls

Most residential and light commercial construction is based on “box” design. In box design, horizontal diaphragms (e.g., roof and floor systems) work in conjunction with vertical shear walls to support gravity loads, resist lateral loads, and provide structural stability. In wood and light-gauge steel-framed construction, the diaphragms and shear walls (called “braced wall lines” or “braced wall panels” in many codes and standards) are constructed similarly. Both use framing members (such as dimensional lumber, engineered lumber, or light-gauge C-shaped steel members) surfaced with structural sheathing (typically plywood or OSB). The IRC and IBC provide prescriptive, framed, shear wall designs that may be incorporated into the building design to resist lateral loads. The prescriptive designs specify requirements for wall bracing, braced wall lines, and braced wall panels.

**DEFINITIONS**

**Shear Wall** – Walls used in building construction that aid in transferring lateral loads from the roof system or walls down to the foundation.

**Diaphragms** – Either roof or floor systems that transfer lateral loads to the shear walls or to the foundation.

Nearly all homes have exterior shear walls. Relatively long homes, large homes, or homes with large openings in the exterior walls may have interior shear walls, as well. Engineered homes with large window or door openings may use moment frames to resist lateral loads in addition to shear walls. While constructed similarly, diaphragms and shear walls act in different ways as they both work to transfer loads down to the foundation of the structure.

The edges (or ends) of diaphragms and shear walls are critical. When diaphragms and shear walls are connected, it is critical that this connection allows loads to be passed in order to ensure that these components will function together as a system. Figure 7-1 illustrates how the shear wall transfers the

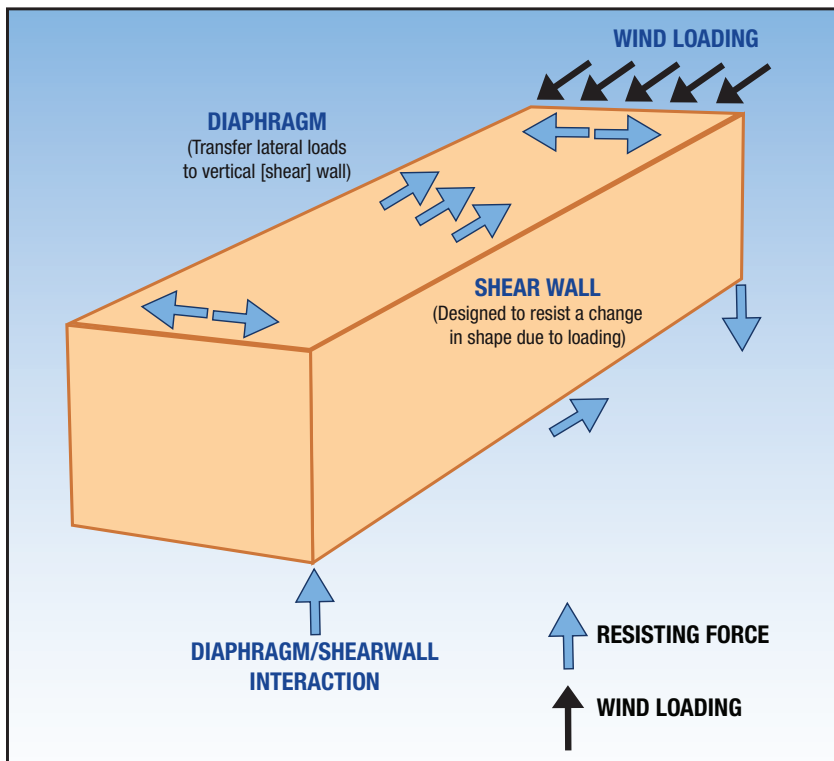
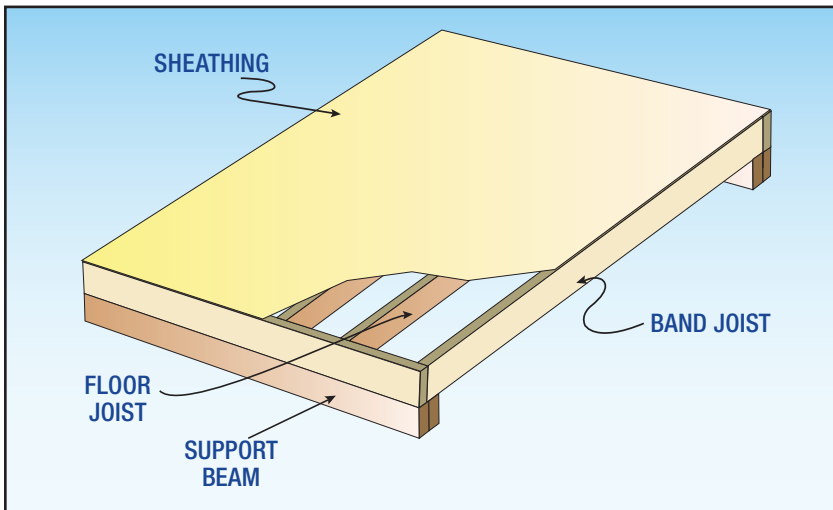


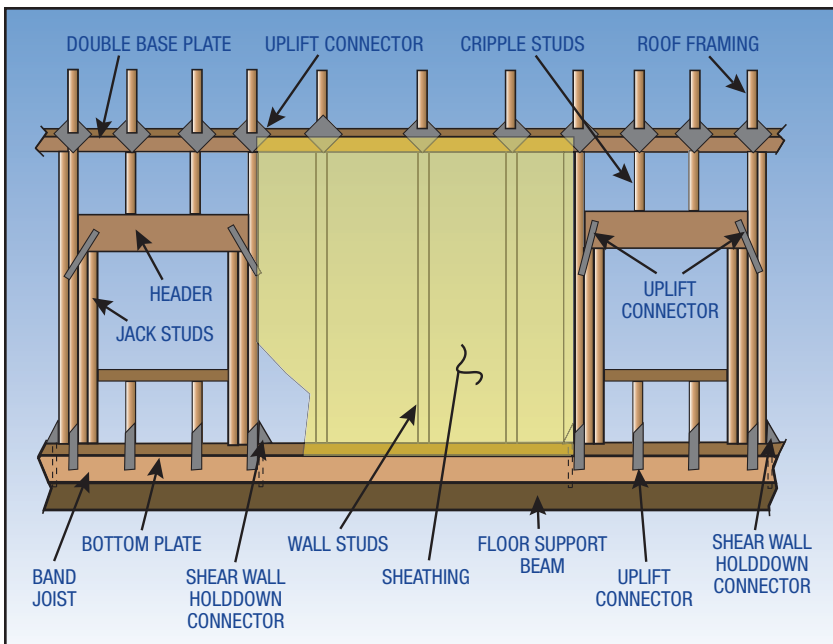
Figure 7-1. Load transfer between diaphragms and shear walls.

loads applied to the roof through the walls and down into the foundation of the house. This chapter provides valuable information that explains what is involved in creating a proper connection in the wall and framing systems of coastal buildings.

When wind forces act on a building, transferring these induced loads through the house will require connections to transfer the loads into the shear wall through both compression (pushing) and tension (pulling). It is important that all of the elements of the building work together in order to create the maximum amount of structural strength and allow the building to maintain its shape and not compromise the building envelope. A failure in the connection or any of the members could result in structural failure. Post-disaster investigations have repeatedly observed roof collapses and wall failures that are representative of the inability to provide a proper connection at this location in the load path. Figures 7-2 and 7-3 show the detailing required in order for the diaphragms and shear walls to maintain their rigidity and shape so that proper connections are maintained.



**Figure 7-2.**  
Horizontal diaphragm and diaphragm components.



**Figure 7-3.**  
Vertical shear walls and shear wall components.

Many of the requirements in prescriptive codes and standards are intended to ensure that buildings are constructed with adequate floor and roof diaphragms and shear walls. Specifically, the IBC, IRC, WFCM, and ICC-600 provide prescriptive shear wall details and designs that may be applied when certain basic conditions are met. Table 2304.6 of the 2006 IBC lists the minimum thickness of wall sheathing and maximum wall-stud spacing for various types of wooden shear-wall applications; Table R602.3(1) of the IRC prescribes a fastener schedule for wooden structural members used in wall construction. Similar prescriptive measures exist in other codes and standards and vary with material type.

### 7.3 Roof Construction

Post-disaster evaluations of coastal buildings damaged during high-wind events have consistently shown that structural failures often begin with the roof. Winds can remove roof coverings from the roof sheathing, tear roof sheathing from supporting framing (see Figure 7-4), and rip roof framing from supporting walls. The loss of roof coverings and roof decking can allow water to enter a building and damage or destroy interior finishes and contents, or even worse, may destabilize a structure and lead to building collapse.



**Figure 7-4.**  
**Loss of roof sheathing due to inadequate fastening between roof sheathing and framing.**  
(Source: FEMA 549)

The structural integrity and successful performance of the roof structure during high-wind events depends upon: 1) adequately designed and spaced roof-framing members, 2) adequate lateral bracing to support roof framing, and 3) adequate connections between the roof structure and the top of the wall to create a complete vertical load path. The roof structure (consisting of the roof framing, roof decking/sheathing, and any internal bracing) also functions as a horizontal diaphragm and transfers the horizontal loads imposed on the roof to the supporting walls below.

Roof failures are often observed on areas of the building where wind pressures are concentrated. These areas include the high-pressure eave and corner zones, porch and roof overhangs, gable ends, and where roof framing joins bearing walls or beams. The connection of the sheathing to the supporting members in these areas is most critical and often may be detailed with a higher density of connectors than other roof areas.

### 7.3.1 Roof Sheathing

Roof sheathing is the first structural component in the load path between the roof system and the foundation. The first envelope components (i.e., the roof covering and roof underlayment) are typically non-structural and are discussed in detail in Chapter 8, *Roof Covering and Best Practices*.

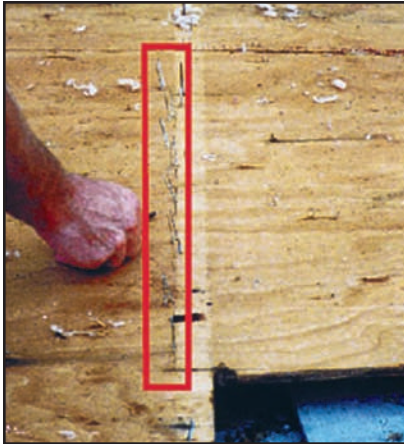
The roof sheathing supports gravity loads, such as the roof live load, snow load, and vertical-uplift loads created by wind pressures. Also, the roof sheathing (working in conjunction with the roof framing) must function as a diaphragm to transfer lateral loads to the building's shear walls.

The IBC, IRC, WFCM, and ICC-600 all contain prescriptive requirements for fastening roof sheathing. The fastening requirements are those required to resist uplift forces from wind pressures and shear forces from lateral loads.

Most codes and standards allow the use of common nails to connect sheathing to supporting members for sites where basic wind speeds are less than 100 mph (110 mph in non-hurricane-prone regions) but require ring-shank nails in higher-wind zones. Ring-shank nails have higher withdrawal capacities (expressed in ratings) and are needed because they provide resistance to the high forces acting on the sheathing panels from the roof pressures in higher-wind zones. Another option is to use wood screws in place of nails because they tend to have higher withdrawal capacities. Best practices recommend the use of wood screws—particularly in the eaves and corner zones of the roof, where winds can create large uplift (suction) pressures. Unless directed otherwise by design professionals, wood screws should have (at a minimum) the same diameter as the nails prescribed by the codes or standards and should be located according to the same spacing interval (or be even more closely spaced). It is also important to note that the density of the roof framing member must be taken into account when determining fastener spacing. Relatively dense framing (such as is achieved with Southern Yellow Pine members) holds fasteners better than lower-density framing (such as Spruce Pine Fir members) and may allow for wider spacing of fasteners.

The fasteners securing roof sheathing must penetrate into the supporting roof framing to prove effective. “Shiners” (i.e., nails that miss roof framing when hammered into place and whose metal surfaces “shine” when viewed from the attic space below) provide no strength and no withdrawal capacity and constitute a discontinuity within the load path (see Figures 7-5 and 7-6). Also, fasteners should not be overdriven. Overdriving the fasteners increases the potential for the roof sheathing to tear around the heads of the fasteners as the nail head penetrates into the wood sheathing. The overdriving of nails frequently occurs when pneumatic or gas-powered nailers are used without proper settings. This issue can be addressed onsite by a contractor by properly calibrating the tools being used.





Figures 7-5 and 7-6.  
Exterior and interior views of connection issues between the roof sheathing and the top chords of the roof truss system. (Source: FEMA 55)



Wood structural panels are rated according to their ability to span between structural members. The prescriptive portions of the IBC and IRC list the minimum thickness of sheathing depending upon the spacing of the roof framing. For example, Table 2304.7(1) of the IBC gives minimum net thicknesses of lumber that may be used in floor and roof sheathing. Table R803.1 of the 2006 IRC prescribes minimum net thicknesses of sheathing depending on rafter-beam spacing for lumber roof sheathing. Section 307.4 of SST-10 specifies minimum 15/32-inch roof sheathing unless other thicknesses are required for adequate roof diaphragm strength. Table 3.12A of the WFCM specifies sheathing based upon the design-wind speed and the spacing of the roof framing for the Exposure B category of wind exposure. WFCM Table A3.12A relates to more stringent Exposure C conditions. Higher basic wind speeds and wider roof-framing spacing requires thicker roof sheathing. WFCM Table 3.12B specifies roof sheathing requirements for snow loads. In areas exposed to both snow and wind loading, the most stringent requirement applies.

A final comment on roof sheathing: It is important to note that the unsupported edges of roof sheathing can flex excessively under load. The American Plywood Association suggests that support be provided for panel edges exposed to walking loads (such as floors and lower-sloped roofs). The use of solid blocking is considered best practice as a means of support, but H-clips can be used for additional edge support. When utilizing H-clips, it is important to consult the manufacturer's spacing requirements to ensure that adequate structural support is attained with the clips.

### 7.3.2 Roof Framing

Roof framing is the next building component found within the load path. The roof framing must support the roof decking and sheathing and resist loads applied to the sheathing and transfer loads vertically to support walls (or frames). The roof framing must also function as part of the roof diaphragm to transfer lateral loads to the shear walls below.

Roof framing typically consists of dimensional lumber rafters or engineered roof trusses. For rafters, design professionals can calculate rafter sizes or sizes can be determined by prescriptive span tables, such as those contained in the AF&PA's *Span Table for Joists and Rafters* or Table 12 of the WFCM. The IBC and IRC also contain span tables. Rafters must be sized to resist dead loads (i.e., the weight of the roof system including rafters, sheathing, roofing, and underlayment, plus any permanent attachments), roof live load, snow load, and wind load. Roof framing must also be sized to control deflections. In areas where the snow load is less than 20 psf, wind loads often dictate the sizing of rafters. In all areas, the most stringent loading must be determined and the rafters sized appropriately.

Connections to resist uplift and adequately transfer lateral loads can be determined by a design professional or from prescriptive standards. Table 3.4 of the WFCM lists the required capacity of the connections between the roof framing and walls (framing or other). Prescriptive designs for toe-nailed connections are provided in Table 3.4A; connections using 20-gauge galvanized straps are listed in Table 3.4B. Tables 3.4, 3.4A, and 3.4B cover Exposure B conditions. Exposure C conditions are detailed in Tables A3.4, A3.4A, and A3.4B. An example of a masonry wall-to-roof truss uplift connection is shown in Figure 7-7.

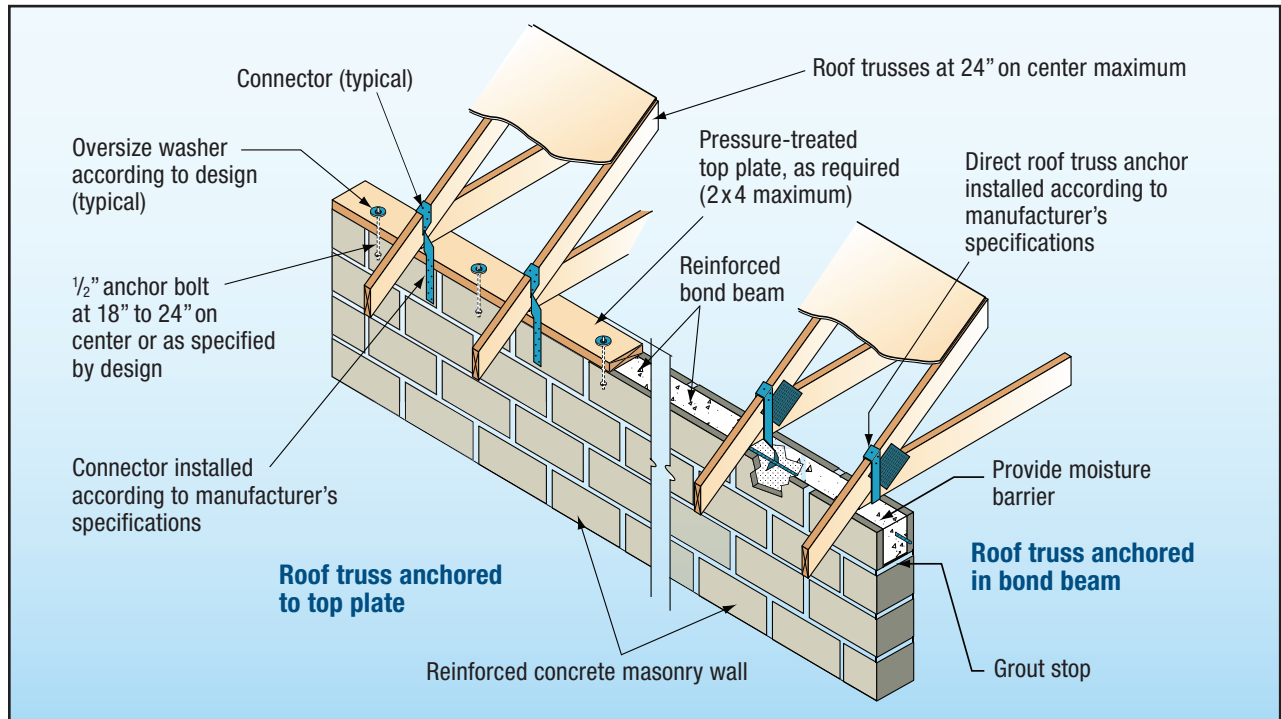


Figure 7-7.  
Detail of masonry wall-to-roof trusses. (Source: FEMA 499)

For trussed roofs, the truss manufacturer typically also serves as the truss designer. Therefore, the truss manufacturer is charged not only with providing specific details relating to truss construction (e.g., the size of members and truss plates) but also with indicating the need for field-installed truss bracing that may be required to prevent buckling of compression members. All truss bracing must be properly installed as directed in the plans, in order for the trusses to function as intended. The truss designer generally specifies bearing and uplift reactions, but does not specify which connectors should be used to secure the trusses. Building officials and plan reviewers should pay careful attention to ensure that all appropriate information (such as the basic wind speed) has been provided on truss drawings by the manufacturers and to identify what additional information must be provided by the builder. A copy of the truss drawings should be required as part of the permit submittal. Providing connectors that may be needed to resist uplift and provide a continuous load path at this location within the load path is not the responsibility of truss manufacturers; the use of these connectors must be determined and specified by others. The use of connectors may be recommended either by design professionals or by prescriptive standards, such as the WFCM.

Information on roof-frame inspection points can be found in FEMA 55, Table 13.6: *Roof Inspection Points*. The table and the associated discussion provides the local official with common roof construction items that should be noted, as well as a summary of topics described in detail within this section.

## 7.4 Wall Construction

Exterior walls are the next building component found within the framing's load path from the roof to the foundation. Like the roof, exterior walls must resist loads imposed on them (particularly by wind or seismic activity) and typically must function as assemblies to provide stability for the entire structure.

Three types of loads can be imposed on exterior walls. First, out-of-plane loads (i.e., loads that exist out of the plane of, or perpendicular to, the wall) are imposed on the walls. These loads result primarily from wind but can also result from seismic activity. All exterior walls are exposed to these out-of-plane forces.

Secondly, vertical loads (also called axial loads) are transferred into some walls from the roof (or upper-story walls) above. The vertical loads can be downward-acting gravity loads that result from the weight of the structure or upward-acting (uplift) loads from wind or seismic events. Uplift and gravity loads are considered in-plane loads since they occur within the plane of the wall, but act along the vertical axis of the wall. All load-bearing walls are exposed to in-plane gravity loads (such as the dead loads of non-load-bearing walls). In addition to the in-plane gravity loads, many walls are also exposed to uplift loads.

Lastly, in-plane horizontal loads can also exist in some walls. These loads typically result from wind forces imposed on building surfaces that are perpendicular to the walls. For example, wind loads acting on a building's roof and front wall create horizontal loads in its left and right walls. Those horizontal loads are collected through horizontal diaphragms such as floors and roof decks, and are called "shear loads." The walls that are needed to resist these loads are called "shear walls" or "shear panels." Shear loads are in-plane loads since they occur within the plane of the wall. Shear walls may also be needed to resist out-of-plane loads from wind or seismic events. In addition, shear walls may function as load-bearing walls. Shear walls that function as load-bearing walls are exposed to all three types of loading (see Figure 7-8).



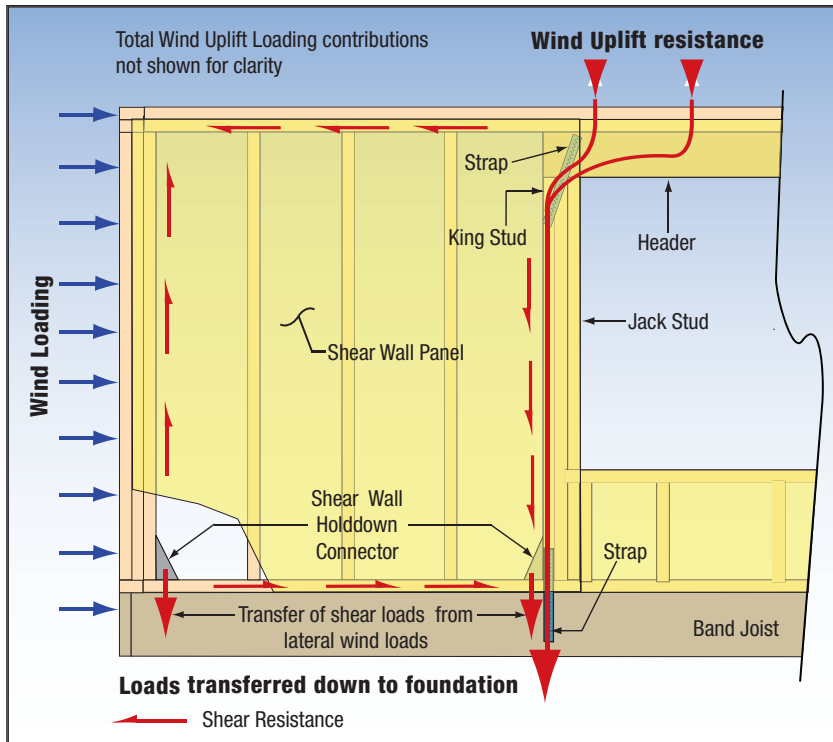


Figure 7-8.  
Horizontal loadings exerted on exterior walls.

#### NOTE

Although exterior walls are typically framed with 2 by 4 lumber, the use of 2 by 6 lumber should be considered. Using 2 by 6 lumber increases the strength of the exterior walls and offers a larger cavity for insulation, thus increasing the energy efficiency of the building.

### 7.4.1 Wall Sheathing

As mentioned in the previous section, all exterior walls must resist out-of-plane forces. Section 602 of the IRC specifies minimum wall-sheathing thickness and fastening requirements for structural panels, plus a variety of other sheathing styles (such as cellulosic fiberboard and gypsum sheathing). Table 3.11 of the WFCM specifies minimum wall-sheathing thickness for structural sheathing based on stud spacing for Exposure B conditions. Exposure C conditions are specified in WFCM Table A3.11.

While cellulosic and gypsum sheathing is accepted by the IRC as wall sheathing, FEMA and others recommend installing wood structural panel sheathing for all exterior walls as a best practice. It was observed during post-event evaluations that wood structural panels perform better and are more resistant to windborne debris than other sheathing materials that are allowed by building codes for the provision of shear resistance.

### 7.4.2 Shear Walls

Shear walls provide lateral stability for a structure. Section R602.10 of the IRC provides prescriptive construction details and requirements for braced wall lines and braced wall panels for buildings exposed to 3-second gust basic wind speeds less than 110 mph (less than 100 mph in hurricane-prone areas). The WFCM provides prescriptive shear wall details for 3-second gust wind speeds from 85 mph to 150 mph. In addition, Section 305.4 of SSTD-10 provides shear wall designs appropriate for use in buildings exposed to wind speeds up to 110 mph (fastest mile).

Shear walls may also be constructed with masonry, concrete, ICF (Insulated Concrete Forms) and with structural insulated panels (typically referred to as SIP). SIPs consist of wood structural panels which sandwich a rigid insulation core, which is typically polystyrene (although urethane is also used).

When analyzing shear walls, two classifications of shear walls exist. Segmented shear walls are full-height, fully sheathed wall segments that function independently to resist lateral loads (see Figure 7-9).

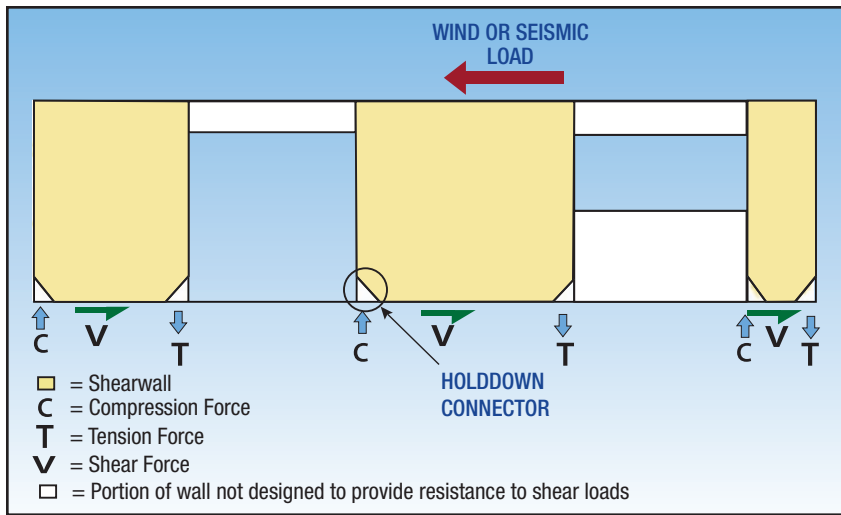


Figure 7-9. Segmented shear walls.

Perforated shear walls contain framed openings for windows and doors. Perforated shear walls rely upon continuous structural elements over windows and door openings to make the shear wall function as a single unit (see Figure 7-10). These elements are called “drag struts.”

For wind design, the WFCM lists the total lengths of segmented shear walls required in a home in Exposure B areas for winds perpendicular to the roof ridge (Table 3-17A) and parallel to the roof ridge (Table 3-17B). Exposure C requirements are listed in Tables A3-17A and A3-17B. Seismic requirements are listed in Table 3-17C.

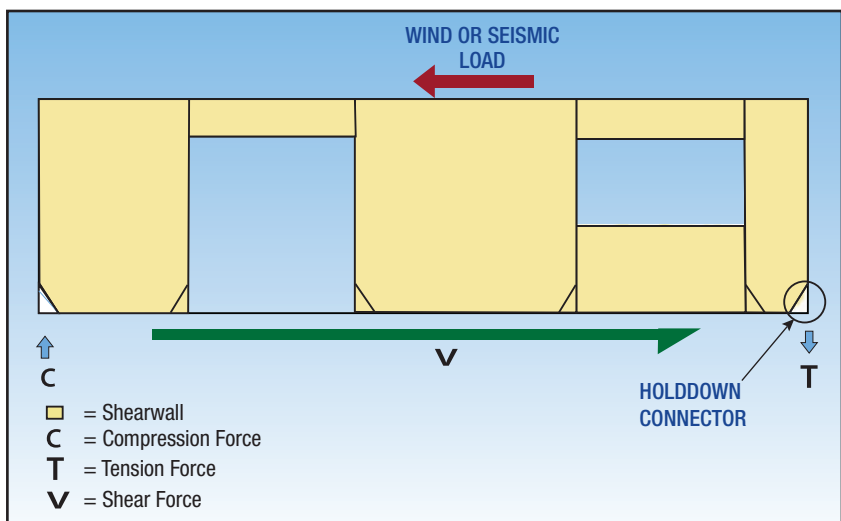


Figure 7-10. Perforated shear walls.

**NOTE**  
Special care should be used when utilizing or checking a design based upon the WFCM tables (or any prescriptive tables) to ensure that all appropriate adjustment factors are being correctly applied.

Per WFCM Section 3.4.4.2, the shear wall lengths tabulated are based upon a standard shear wall. The standard wall is a blocked<sup>1</sup> shear wall constructed with 7/16-inch wooden structural panels attached with 8d nails 6 inches on centers (at panel edges) and 12 inches on centers (within the interior of the panel, also called the “field”). The inside surface of the standard wall or shear wall panel (i.e., the surface that is exposed to the finished/living space) is surfaced with  $\frac{1}{2}$ -inch gypsum drywall secured with 5d cooler nails at 7 inches on centers along edges and 10 inches on centers within the panel. These standard shear walls provide a shear capacity of 436 pounds per linear foot. Adjustment factors for variations on standard shear wall construction are provided in Table 3.17D. Shear walls with lower shear capacity require longer wall lengths; walls with higher shear capacity require shorter wall lengths.

The WFCM contains criteria needed for constructing perforated shear walls. The criteria are determined by multiplying the tabulated shear wall lengths (in feet) listed for segmented shear walls in Table 3.17A, 3.17B, or 3.17C by adjustment factors listed in Table 3-17E for perforated shear walls. The adjustment factors in Table 3.17E are based upon the size and aspect ratios (height/width ratios) of the framed openings within the perforated shear walls. Tables 3.17A and 3.17B list the minimum segmented shear wall lengths required to resist wind loads. (Table 3.17A is for shear walls parallel to the wind and Table 3.17B is for shear walls perpendicular to the wind.) While Tables 3.17A and 3.17B address shear wall requirements to resist design wind events, Table 3.17C lists shear wall requirements for seismic events. Like Tables 3.17A and 3.17B, Table 3.17C provides the required length of segmented shear walls (in feet). Unlike Tables 3.17A and 3.17B (which list the minimum lengths of shear wall segments), Table 3.17C contains formulas necessary to determine those lengths.

For example, if Table 3.17A requires a minimum of 15 feet of shear wall segments be provided to resist winds perpendicular to the ridge and Table 3.17E lists a perforated shear wall adjustment factor of 1.33 based upon the size and aspect ratios of openings within that wall, then 20 feet (15 feet x 1.33) of perforated shear wall must be provided.

Generally, greater lengths of perforated shear walls are needed to resist lateral loads than segmented shear walls. Also, in perforated shear walls, more attention in the detailing and design is needed above doors and windows, where framing functions as drag struts. The greater attention is needed to ensure that the drag struts and their connections are adequate to transfer in-plane loads through the shear wall. The benefit of perforated shear walls is that they only need to be anchored at their ends while the ends of each segment of a segmented shear wall need to be anchored. This is discussed in the following section.

### 7.4.2.1 Shear Wall Anchorage

Shear walls (whether segmented or perforated) must be anchored to the foundation<sup>2</sup> (or the shear wall below when on an elevated floor) to complete the continuous load path within this area of the building. A proper anchorage or connection prevents the shear walls and, in turn, the rest of the structure from laterally racking, displacing, or overturning during a high-wind or seismic event.

<sup>1</sup> Blocking is short framing members installed between wall studs or floor joists. Blocking provides a method to fasten the unsupported edges of sheathing panels.

<sup>2</sup> Small, relatively heavy homes (or homes placed in low-wind areas) may have sufficient weight to avoid requiring shear-wall anchorage. Even in such instances, shear-wall anchorage is advised for structural redundancy.

Segmented shear walls need to be anchored at the edges or ends of each shear wall panel. Perforated shear walls typically only need anchorage at their ends. Figure 7-11 illustrates a typical large anchor that may be connected at the end post of a framed shear wall.

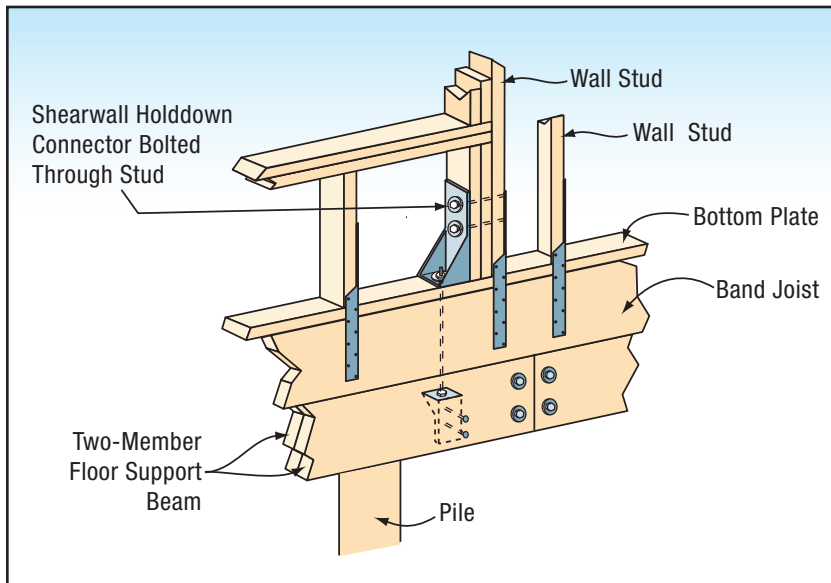


Figure 7-11.  
Shear wall anchor. (Source: FEMA 55)

Shear wall anchorage capacities for multi-level buildings are additive. In other words, anchorage for upper-level shear walls needs to be provided in addition to first-floor anchorage. Where segmented shear wall panels line up vertically, the panels can share anchorage devices—provided the anchorage device is capable of resisting the total load for all shear panels that it anchors. The same is true for the ends of perforated shear walls. Multi-level perforated shear walls can share anchorage at their ends, provided the anchor is capable of resisting shear wall reactions for all levels.

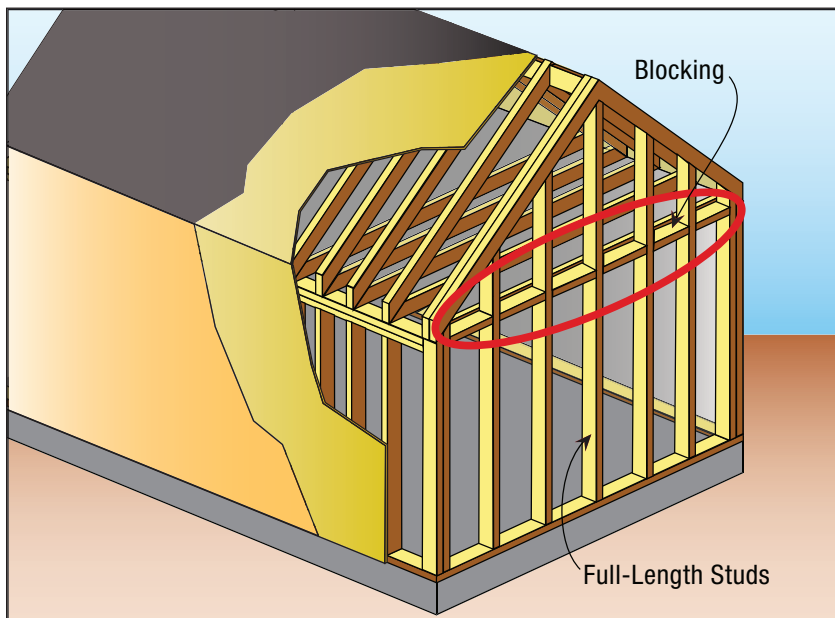
The reactions (loads) at the ends of shear walls are proportional to wall height. Taller walls develop larger reactions and require stronger anchors, and anchorage requirements for even small homes can be thousands of pounds. Table 3.17F of the WFCM lists hold-down requirements (in pounds) for wall heights ranging from 8 feet to 20 feet. Many anchor types and styles are available and should be designed based on the manufacturer's published anchor capacities. An example of an anchor is shown in Figure 7-11. For load-path continuity, anchors should extend from shear wall to shear wall (if the building has several levels) and eventually into the foundation. Shear wall tie-downs generally resist or transfer vertical loads only; other fasteners are needed to resist the horizontal loads (called *base shear*) that accompany wind or seismic events.

### 7.4.2.2 Gable End Walls

Gable end wall failures continue to be observed after hurricanes impact structures. The gable end walls are those that are oriented parallel to roof/floor framing and extend past the top plate of the wall framing and up to the roof ridge. Gable end walls do not support the roof and do not benefit from the lateral support that the roof framing provides unless they are joined by structural members or connectors.

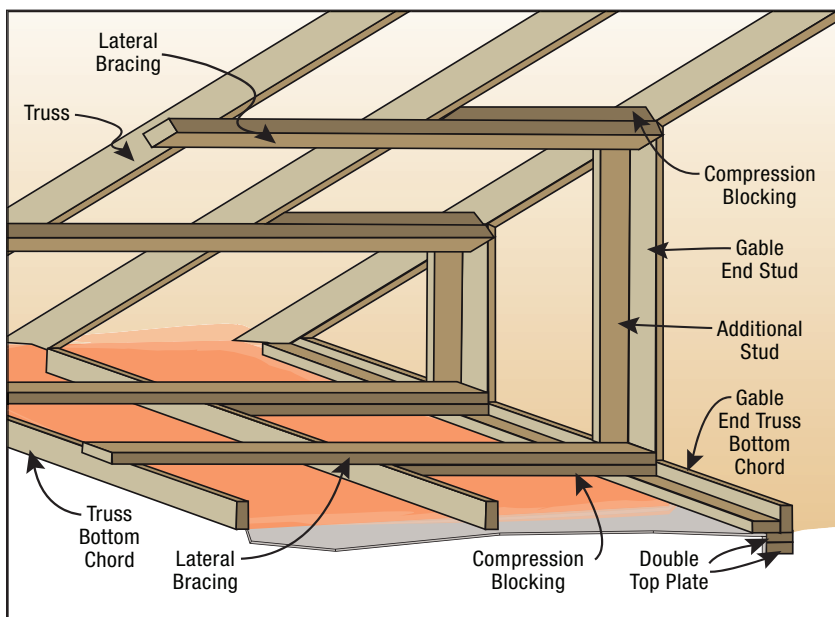
Gable end wall construction requirements are reasonably well-detailed for masonry and concrete but less guidance is provided for wood framing. Figure 205E4 of ICC 600 contains a detail of gable end bracing for a masonry wall with a wood-framed gable (see Figure 7-13), but ICC 600 does not provide details on bracing a wood-framed gable atop a wood-framed (or metal stud) wall.

Figure 305J of SSTD-10 indicates that gables should be balloon-framed (with vertically continuous studs across the ceiling diaphragm (see Figure 7-12) and Figure 305K of SSTD-10 shows platform-constructed gable walls (i.e., those constructed with a top plate) but only shows walls being secured to the finish sheathing of the ceiling diaphragm, and not a structural member from the roof-framing system. SSTD-10 Section 306.3 specifies the use of bracing ceiling joists/truss bottom chords with 6-foot-long lateral braces at maximum 6-foot intervals, but the bracing is not shown in the graphic details.



**Figure 7-12.**  
Example of balloon framing.

**NOTE**  
Balloon framing is a construction technique reserved for specific applications and cannot be used in certain applications, due to restrictions on the height of members. It is typically possible for one-story houses, but balloon framing does not usually work for two-story houses.



**Figure 7-13.**  
Additional bracing at a gable end wall.

**NOTE**  
Gable end walls may be constructed through a variety of different building materials and techniques, but the discussion presented here is primarily focused on framed construction.



As a best-practices approach, the ceiling diaphragm should be constructed with wood framing and the gable end wall should be braced to that framing. IBHS (Institute for Business and Home Safety), FEMA, and other entities have developed methods to brace wood-framed gables to wood-framed walls. Figure 7-13 provides an example of a gable end wall bracing scenario. (The “Hurricane Retrofit Guide,” available at <http://www.floridadisaster.org>, provides several examples of various framing situations.)

Taller gables may lack adequate framing to resist wind loads and pressures; bracing the mid-point of longer studs used in tall gable end walls may be necessary in order to meet design loads. Design professionals can design and detail the bracing for taller gable walls.

Gable walls on buildings with cathedral ceilings often have an added disadvantage. With cathedral ceilings, the top plate of the building’s gable wall may be offset from the sloped ceiling diaphragm (see Figure 14). When offset, the ceiling diaphragm cannot provide lateral support for the portion of the wall where the top plate is located—an area that is inherently weak and vulnerable to out-of-plane forces acting on the wall.



**Figure 7-14.**  
**Improperly braced gable walls.**  
The ceiling diaphragm (i.e., the bottom chords of the scissor truss) is located several feet above the top of the end wall top plate and no wall-to-truss bracing is provided. (Source: FEMA 549)

To address gable end wall weaknesses that may exist, proper bracing is needed. For conventional framing, augmenting the code-referenced bracing methods with cross-bracing secured to the rafters and ceiling joists (or to the top and bottom chords of roof trusses) is suggested (see Figure 7-13). For buildings framed with cathedral ceilings, two actions are recommended. First, the gable ends should be balloon-framed and constructed so wall studs continue unspliced across the ceiling diaphragm. Secondly, the upper portion of the framing should be braced as detailed for conventional gable ends.

### 7.4.2.3 Interior Shear Walls and Moment Frames

Occasionally, buildings are laid out in such a manner that insufficient space has been allocated for the constructing of adequate “standard” exterior shear walls to resist lateral loads. This can occur with relatively long and narrow buildings or when (as in the case of many coastal homes) designers and

homeowners want to maximize the amount of windows installed in a home. In such cases, a few options exist for providing lateral load-resisting systems.

A first option to address the lack of exterior shear walls involves making the exterior shear walls stronger in order to resist greater shear forces. Installing structural panels on both sides of the wall framing can increase (and will typically double) the load capacity in a shear wall. Keep in mind that with larger shear forces, shear forces at tie-downs become greater and adequate tie-down and anchorage become more difficult to achieve.

A second option is to construct interior shear walls. Interior shear walls are typically designed to be stronger (i.e., have more load capacity) than exterior shear walls because interior shear walls resist shears collected from diaphragms located on both sides of the interior shear wall (while exterior shear walls only collect loads from diaphragms on one side). Interior shear walls typically need to be located over foundation walls or over a line of pilings or piers. This is required to ensure that the reactions developed in the shear walls can be adequately transferred to the foundation.

A third option is to construct interior moment frames. Further, moment resistant frames are considered specialized construction and are not addressed in prescriptive codes or standards. To ensure adequacy, therefore, moment resistant frames should be designed by a structural engineer. Once designed by the engineer for the appropriate wind and flood loads, the fabrication of steel moment resistant frames will usually be performed by a subcontractor that specializes in steel fabrication and erection and who should first prepare a set of shop drawings from the design drawings for review by the building department. The contractor and designer should both check the accuracy of the subcontractor's shop drawings. Most moment resistant frames will have to be transported in sections and assembled onsite through field bolting or welding (see Figure 7-15).



#### DEFINITION

**Moment Resistant Frame** – A series of columns and beams which resists lateral loading through its ability to bend. Typically utilized in residential construction, moment resistant frames are often used in combination with shear wall systems.

Figure 7-15.  
Residential use of a moment resistant frame. (Source: FEMA 55)

### 7.4.3 Headers, Beams, and Girders

Headers are horizontal beams constructed to support loads over framed openings. Headers are typically required over all openings in exterior walls and over all interior load-bearing walls. Headers support not only gravity loads (e.g., live loads, snow loads, and dead loads) but must also resist uplift loads from wind events (see Figure 7-16).

Tables 3.22A through 3.22E of the WFCM contain header sizes for gravity loads for various building types (single-, two-, and three-story), various building widths (from 12 to 36 feet), and ranges of ground snow loads (from 30 to 70 psf). Table 3.23A provides header sizes for openings in walls exposed to wind loads for 3-second gust wind speeds up to 150 mph. In areas where the 3-second gust basic wind speed is 110 mph or less, gravity loads typically control header size. In areas where the 3-second gust basic wind speed exceeds 110 mph, wind loads may control. Both tables need to be checked and the most restrictive of them should be used to determine header size. Table 3.23A relates to Exposure B conditions; Exposure C conditions are listed in Table A3.23A in Appendix A of the WFCM.

Each end of headers should have uplift connectors to resist wind uplift forces and to complete the load path. The wind forces that connectors must resist in Exposure B areas are tabulated in WFCM Table 3.7; uplift forces for Exposure C areas are tabulated in WFCM Table A3.7. The uplift connections are based upon a roof dead weight of 15 psf (and other criteria that must be met for these tabular values to remain valid for a particular application). It should be noted that these values are conservative for heavier roof structures. For buildings with lighter roof structures, uplift loads need to be determined by a design professional.

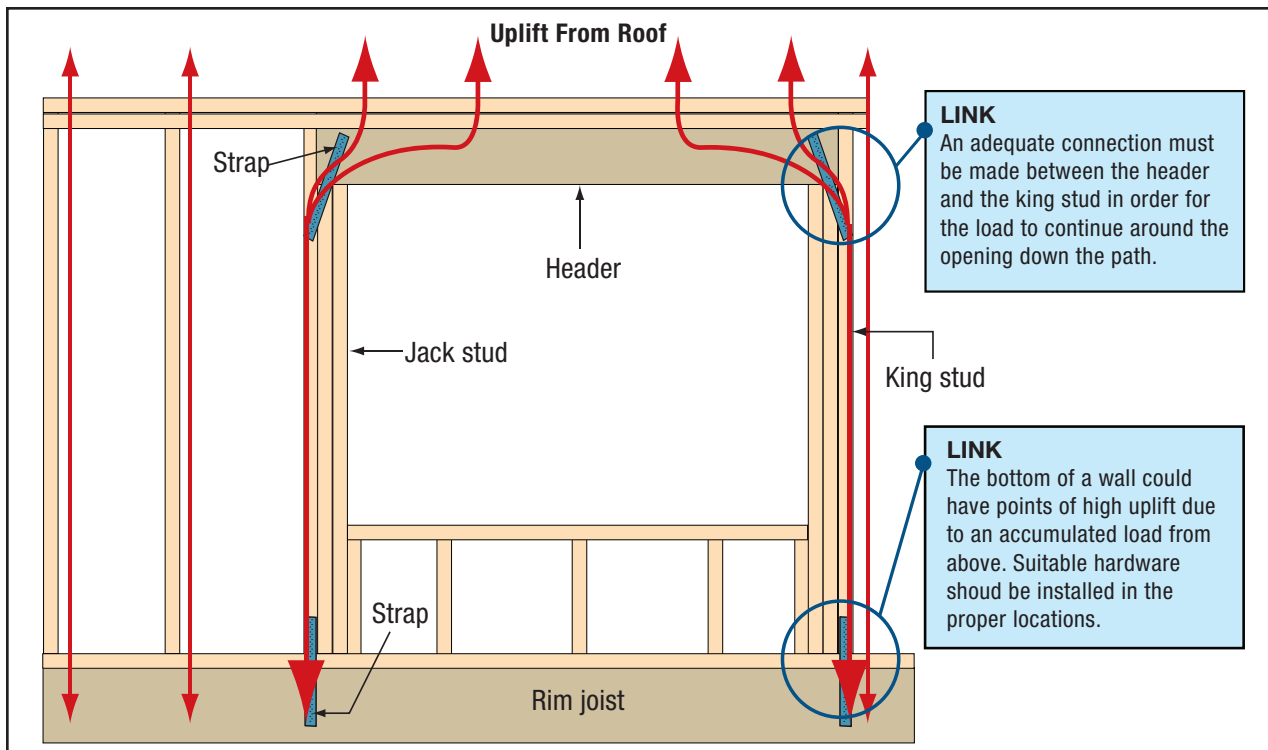


Figure 7-16.  
Uplift connections for headers. (Source: FEMA 499)

The bottoms of framed openings for windows also need to be properly connected to resist out-of-plane loads. Window-sill plates are sized in Tables 3.23B (Exposure B) and A2.23B (Exposure C); and lateral forces acting on window sills must also be resisted. These loads are tabulated in Tables 3.8 and A3.8 for Exposure B and C areas, respectively.

Girders are horizontal members which collect loads and support floor framing and floor joists. Girders connect the floor systems to the columns or posts of the foundation. Unlike headers (which are constructed integrally with walls that can resist shear), the girders and posts used in wood-framed construction are typically not parts of the lateral load-resisting system and are used to support gravity loads only.

Table R502.5(1) of the IRC provides prescriptive designs for girders based upon the distance between supports, number of floors supported, and width of the home. The table lists requirements for dimensional lumber and specifies the use of built-up beams with a thickness of up to four plies. The table is based upon simply supported beams where individual members of the beam are spliced over the supports. In the IBC, Tables 2308.9.5 and 2308.9.6 provide wood-header and girder-span requirements for exterior and interior load-bearing walls, respectively. The spans are a function of the building construction type (one- or two-story dwellings), header or girder size, and building width.

Designing built-up beams (where some of the members are used in a continuous manner over the supports) will: 1) result in more efficient designs that require less framing material, and 2) typically result in significant reductions in deflection. Wherever a splice is made, the spliced member does not contribute to beam strength, so correctly locating splices is critical for ensuring proper performance. Splices need to be placed in locations where induced moments in the beam are low. Engineers should design beams that are considered to be “continuous” over supports and should detail where splices in the individual members are located. Continuous beams carry moment forces in the beams across the top of the supporting post or column. By contrast, simply supported beams have zero moment at the supporting post or column.

#### 7.4.4 Concrete, Masonry, and ICF Walls

The use of walls constructed from reinforced concrete or concrete masonry units (CMU) is becoming more prevalent in communities impacted by hurricanes. When properly designed and constructed, these styles of walls can perform well when exposed to high winds. Typically, concrete and CMU construction is used in conjunction with wood-framed roofs and, in the case of multi-story buildings, wood-framed floors. Concrete and masonry walls lack the thermal performance required by the IRC and typically require framed walls or thick furring to allow the addition of sufficient insulation. But with the advent of ICF (Insulated Concrete Form) wall sections, sufficient thermal and structural performance can be obtained with a single, reinforced concrete-wall section because its permanent insulating form remains in place. Figure 7-17 illustrates a well-designed masonry wall system.

#### NOTE

Insulating Concrete Forms (ICF) are used in a construction technique that utilizes pre-formed blocks or panels to form a pre-insulated wall system that relies upon concrete for its structural integrity. More information about acceptable ICF applications is available in the IRC.



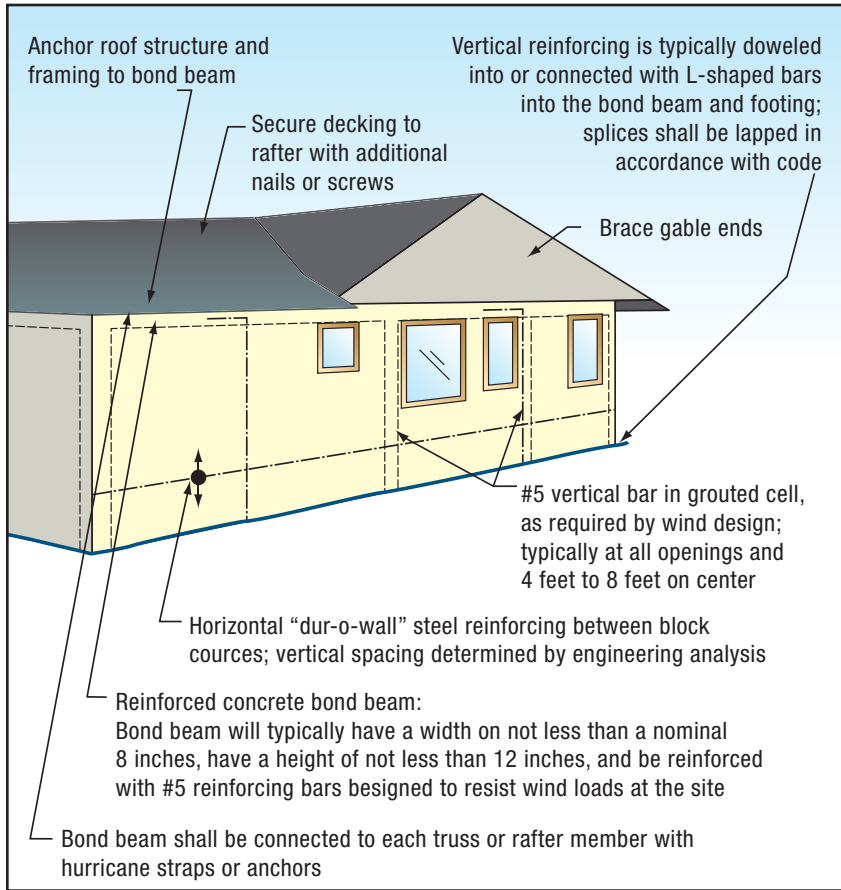


Figure 7-17.  
Design of a reinforced masonry wall system.  
(Source: FEMA 488)

Requirements for masonry shear walls are specified in Sections R606, R607, and R608 of the IRC. The IRC contains some prescriptive designs for masonry walls (e.g., wall reinforcement, minimum width of walls, rafter and joist connections, and floor diaphragm connections), however, there will be some aspects of masonry construction that will need to be designed. For example, IRC Section R606.12.2.2.1 requires that connections to shear walls be designed in accordance with the performance standard ACI 530/ASCE 5/TMS 402, *Building Code Requirements for Masonry Structures*. Requirements for ICF construction are provided in IRC Section R611. The prescriptive designs for ICF are well-developed and detailed.

Examples of prescriptive designs for concrete and masonry walls in high-wind regions are contained in Section 205.5 of ICC 600. It is important to note that reinforcement is specified for walls both parallel to and perpendicular to the roof ridge for one-, two-, and three-story buildings. Prescriptive ICF designs that meet high-wind requirements of the IRC may be found in Section 209 of ICC 600.

Information on wall-framing inspection points can be found in FEMA 55 Table 13.5: *Wall Inspection Points.* This table provides the official with common items that should be inspected or observed in wall-framing construction, as well as a summary of the topics described within this section.

## 7.5 Floor Construction

People are generally quite aware of the floors on which they live and work. People notice the squeak of a loose floorboard, feel the softness of plush carpet, and experience the fatigue that results from standing on hard concrete slabs. Many people are unnerved when floors “give” or deflect too much under foot



traffic. What many people are not aware of is the structural importance of floor systems. In addition to supporting a building's occupants, floor systems are critical components in resisting lateral loads.

Floors (and ceilings) function as diaphragms and collect lateral loads that have been exerted on a building's exterior from wind or flood forces. Floor systems transfer loads either to shear walls in the stories below or, in the case of the lowest floor, to the foundation. Floors and ceilings prevent torsional racking of the building and together constitute a major component of that building's structure.

Older versions of prescriptive codes and standards concentrated on floor construction that resisted gravity loads. Emphasis was placed on the proper sizing of floor joists for adequate strength and deflection control (because deflection of the floor is often the governing criteria when selecting member sizes, spacing, and the maximum span of floor joists). Newer codes and standards (i.e., those issued after 1990) place an increasing emphasis on lateral loads. Details are provided (in the form of prescriptive or performance requirements) to ensure that floor systems function as diaphragms and adequately transfer loads through the structure.

It is recommended that buildings be constructed higher, the NFIP requires structures built in A Zones be elevated to at least the BFE and that all materials below the BFE be flood-resistant. In floodprone areas, elevated wood framed floors, floor joists, floor decking and insulation all need to be flood resistant if they are not elevated above the BFE. This criteria typically requires the framing and flooring to be treated to resist moisture and decay and precludes the use of fiberglass batt insulation.

### 7.5.1 Floor Framing and Sheathing

Like roof framing, floor framing typically consists of dimensional lumber spanning an open area; these members are called "floor joists." The use of engineered wood products such as floor trusses and I-joists (see Figure 7-18) is becoming more common in floor framing, especially when long, open areas are desired beneath the elevated floor. For dimensional lumber, design professionals can determine joist sizes or they can be determined using span tables, such as those contained in the AF&PA's *Span Table for Joists and Rafters* or the WFCM. The IBC also contains span tables for a variety of lumber species and loading conditions.

As mentioned, the use of floor trusses and I-joists is becoming more prevalent in floor-framing systems in many parts of the United States. The proper installation of these materials may require additional steps. For example, some I-joists require solid blocking to prevent web crushing under bearing walls (such as where a wall above is being supported by a floor without the use of a beam or girder). Where longer-span floor framing is installed, blocking is needed for lateral support, as is typical in longer-span dimensional lumber floor-framing applications. When using any engineered product, the manufacturer's installation procedures must be followed to ensure that the system functions as designed.

Floor joists must also be sized to resist dead loads (i.e., the weight of the floor system including joists, floor sheathing, and flooring, plus any permanent attachments) and live loads. In addition, maximum allowable deflections corresponding to beam length are specified in the code and material standards. It is important to note that, in most cases, floor-framing deflection limits are more stringent than roof-framing deflection limits.

Perimeter framing of the floor system must prevent the floor system from racking and function as a collector to transfer forces to the shear walls or foundation below. The IRC, ICC-600, and the WFCM all contain prescriptive requirements for blocking and for connections to walls plates (located above) and sill plates (below).

Gravity and live loads typically control the design or specification of the thickness of floor sheathing. In addition, floor sheathing must be constructed in a fashion to create diaphragms that resist lateral loads. Section 503 of the IRC specifies boards and structural panels to be used as floor sheathing for various joist spacing and floor live loads.

The provisions of prescriptive codes and standards generally address most floor construction situations. They cover many issues that typically arise in a coastal environment. One area, however, where the provision of additional details is warranted concerns the protection of metal fasteners against salt spray. While much discussion on corrosion protection has gone into code development, the corrosion of metal building elements under elevated structures remains a potentially serious problem. Fasteners under elevated structures are exposed to salt spray but are not exposed to the cleansing action of rain. Also, the undersides of elevated structures are not exposed to sunlight and can remain damp longer because of their sheltered location. The use of hot-dipped galvanized fasteners provides connectors with a reduced rate of corrosion (when compared to untreated connectors). But since portions of the galvanized areas are often damaged when nails are driven, even galvanizing is not considered fully effective in resisting corrosion. Stainless-steel connectors provide the most corrosion resistance offered in a metal connector, but the availability of stainless-steel fasteners and framing connectors is limited in some areas.

One method to reduce exposure to salt spray is to sheath the undersides of floor-framing systems in order to enclose the space where connectors are located. Plywood sheathing (at least  $\frac{1}{2}$ -inch thick) is recommended and should be installed to enclose the floor-framing system. Sheathing should be scribed around utility and framing penetrations to reduce the infiltration of salt-laden air. Methods that allow portions of the sheathing to be removed to allow periodic inspection should also be considered and incorporated into any design. Further, since metal-plate wood trusses may become unstable under gravity loads when their metal plates lose strength, metal-plate wood trusses should not be used in coastal environments unless corrosion is adequately controlled.

Information on floor-framing inspection points can be found in FEMA 55, Table 13.4: *Floor Framing Inspection Points*, which provides the official with common items in floor-framing construction that should be noted, as well as a summary of topics described in detail within this section.



**Figure 7-18.**  
Wooden I-joists used for floor framing. (Source: FEMA 55)