DESIGN CONCEPTS

BUILDING IN HIGH WIND AND SEISMIC ZONES

APA

The Engineered Wood Association

BUILDING IN HIGH WIND AND SEISMIC ZONES

In hurricane and earthquake country, builders and designers face the task of creating structures that can withstand high wind and seismic forces. While building codes address the design requirements necessary for all types of construction, many of the prescriptive recommendations are either misunderstood, or are incomplete. Wood frame construction makes it easy for building professionals to construct strong, durable buildings that meet code requirements and assure good performance in severe weather and earthquakes. It is essential, however, that the structure be properly detailed.

When building for seismic and high wind areas, a basic understanding of how lateral loads act on wood framing systems, and how construction detailing and fasteners affect the ultimate performance of a structure is invaluable. Builders and designers can use these principles to ensure strength, quality and safety in both residential and non-residential buildings located in high wind and seismic zones.

Wood: A Strong and Versatile Performer

Wood has inherent characteristics that make it an ideal material in areas prone to earthquakes and hurricanes. The light weight of wood-frame construction results in less force due to inertia during an earthquake. And less force means less damage. Additionally, the flexibility of wood allows a wood-framed building to better absorb and resist the forces found in both earthquakes and hurricanes.

The elements of a wood-framed building that enable it to withstand earthquake or hurricane forces are the shear walls and diaphragms. Such construction systems rely completely on the correct and adequate design and installation of *all* components of that system: framing, structural panel sheathing, and inter-element fastening details. The improper use of any one of these components can have a profoundly negative impact on the ultimate performance of the entire structure.

Proper Fastening and Transfer of Forces

The fastening of wood structural panels over wall framing creates a shear wall element. Similarly, the installation of wood structural panels over roof or floor supports creates a diaphragm. When properly tied together and tied to the foundation, the shear walls and diaphragm elements give a building a tremendous resistance to lateral forces/lateral loads. These lateral forces are generally the result of wind or seismic forces acting horizontally on a building or the racking incurred during seismic events. Lateral loads are often misunderstood or ignored by builders and designers. This is not surprising due to the fact that there is nothing intuitive about lateral loads.

A shear wall or diaphragm cannot effectively act alone in resisting the effects of lateral loads. For the structural system to work, a well constructed roof diaphragm must act to transfer lateral loads to the shear walls and the shear walls themselves must transfer this load into the foundation. The effectiveness of the system is only as good as the quality and quantity of the connections. Thus, the key to constructing a building that can resist lateral loads is understanding connections and the proper transfer of forces.

In hurricanes, loss of roofing materials and sheathing is the leading cause of structural failure in wood framed buildings. The central reasons behind these failures are improper connection detailing between structural systems and inadequate fastening of sheathing to supporting members. Most local codes require a minimum of 33 fasteners for a standard 4x8 panel installed over roof supports 24 inches o.c. Fasteners, such as 8d common nails or other code-approved fasteners, should be placed a maximum of 6 inches o.c. along panel edges and 12 inches o.c. at intermediate supports. Following Hurricane Andrew in Florida, damage assessment teams found roof sheathing panels with as few as four fasteners. Once the roof sheathing has been pulled off the roof framing, the diaphragm ceases to function and the load path has been interrupted.

Similarly, the most common structural failures noted after an earthquake are buildings that rotate on or are forced off their foundations. Again, inadequate fastening and connection detailing are the culprits. In this case, it is the shear wall elements that have been compromised. Increasing the connection of the shear wall to the foundation and using wood structural-panel sheathing to increase the capacity of shear walls in first-story walls can prevent severe damage, especially that often associated with multi-story buildings. Important connection points include where the top of a shear wall is fastened to the second floor or roof framing, and where the bottom of the wall is fastened to the sill plate/foundation.

Anchoring Systems

The Uniform Building Code (UBC) requires sill plates to be fastened to the foundation with 1/2-inch-diameter bolts spaced no more than six feet apart. One bolt also must be placed within 12 inches of each end of each section of the plate. (Similar attachments are required by the other model building codes.) In addition to these "base shear" connectors, additional anchoring with the use of holddowns is sometimes required.

Although cast-in-place anchor bolts are the most common means of attaching a structure to the foundation (also the "code-approved" method), there are other anchoring systems that also may be used, depending on your local code jurisdiction. When anchor bolts are misplaced or left out, epoxy anchors are often the most economical system to use. While cheaper than epoxy anchors, expansion anchors should only be used when there is sufficient clearance between the anchor and edge of the slab to prevent break out of slab/foundation during tightening.

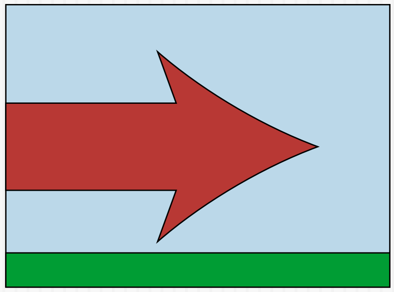
When an object is bolted down – restrained from sliding – and a lateral load is applied, an overturning force occurs. This overturning force must be resisted by the use of connectors called holddown anchors or "holddowns." Utilizing holddowns, these forces can be properly transferred to prevent overturning of structural elements.

In non-residential buildings with tilt-up concrete walls, most damage results from separation of roof-to-wall connections around the perimeter of the roof diaphragm. As required by the building codes, proper connection of roof framing to exterior walls and continuous ties across the roof between walls prevent such damage.

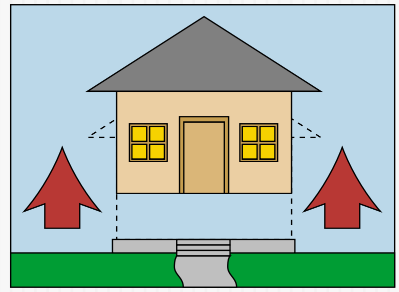
Framing anchors are commonly used in lieu of or to augment traditional fastening systems such as bolts and common nailed connections. They are used in locations where the resulting forces are too great to be handled by nailed connectors. A shear wall holddown anchor is one such example. Capacities for holddown anchors run from 1,500-15,000 lbs. Another location where framing anchors are often used is at roof truss to top plate connections, where forces in three different directions must be accommodated during high wind or seismic events. Selecting the appropriate framing anchor simplifies making such connections.

THE TWO-MINUTE ENGINEER

FORCES

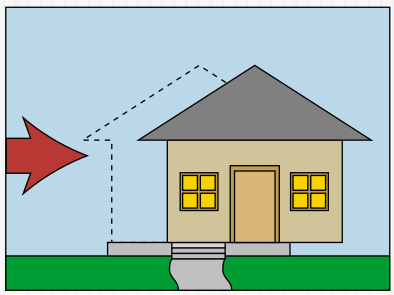


Lateral load: Forces applied parallel to level ground surface. (wind, seismic, backfill, etc.)

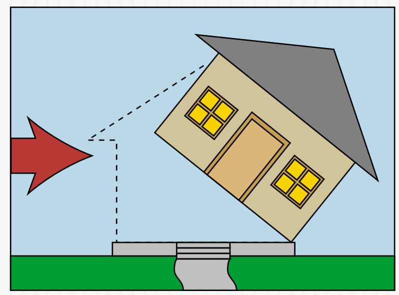


Uplift: Forces applied perpendicular to level ground surface, in an upward direction. (wind uplift and vertical seismic forces)

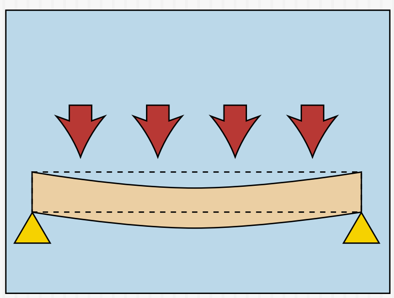
REACTION



Base shear: The reaction at the base of a wall or structure due to an applied lateral load – "Sliding Force."



Overturning: What happens when a lateral force acts on a wall or structure and it can't slide – "Tip Over Force."

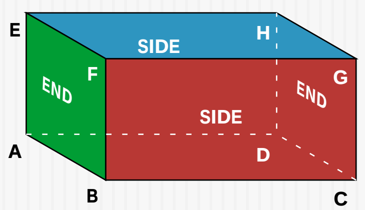


Beam action: Distributes/transfers loads around an opening and into the remainder of the structure – "Bending Force."

Designing for Lateral Loads

When designing for lateral loads, every force that acts on the building must be transferred by the elements in the building and by the connections between those elements into the foundation. This is called the "Load Path." The load path issue can be illustrated with the following building example (Figure 1).

FIGURE 1 **Example structure**



Because an earthquake or hurricane force can act in any direction, the designer must design the structure for forces acting along both the length and the width of the structure. In addition to these two lateral forces, both wind and seismic events cause an uplift vertical force. Thus, there are three forces – all at 90 degrees to each other – acting on every element and every connection between elements. The following example illustrates the lateral load path along one of the two horizontal building axes. The vertical load path is considered intuitive or obvious and thus is not illustrated.

In Figure 2, when endwall EFAB experiences a lateral wind load, one half of the load transfers by beam action of the wall studs to the bottom of the wall at AB (Figure 2a) and then transfers into the ground.

FIGURE 2 **Lateral load acting on an end wall and transfer of resulting forces**

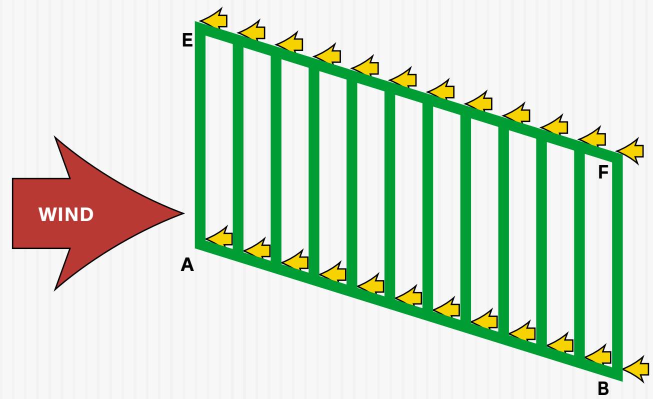


FIGURE 2a **Perimeter anchor bolts – transfer forces into foundation**

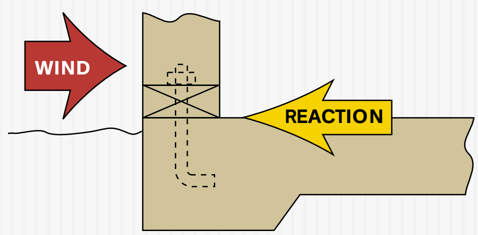
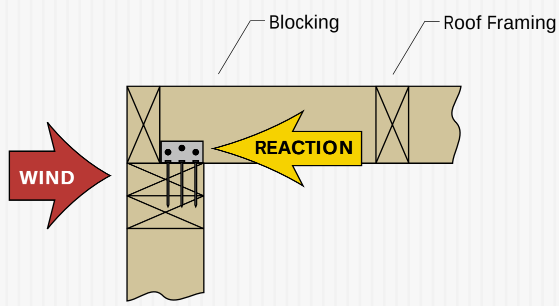


FIGURE 2b **Rafter connection detail – transfers forces into diaphragm**



The transfer of forces into the foundation is accomplished by the perimeter anchor bolts which are loaded perpendicular to the grain of the bottom plate. The second half of the load transfers to the rafters and from these the force flows into the diaphragm (Figure 2b).

As at the bottom of the wall, the fasteners at the rafter connection must transfer forces perpendicular to the grain of the top plate (when designing for the wind forces at the endwall), parallel to the top plate (when designing for the wind forces at the sidewall), and also resist uplift – three forces in three different directions.

Because fasteners at this location must work against multiple forces, mere toe-nailing of roof framing to walls, top plates and other supporting elements is inadequate when used without other fastener systems. A toenail only works well when loaded in one direction, whereas the forces act in three directions. The same goes for holddown straps which prevent vertical separation but give no protection from the lateral forces of high wind.

The forces that accumulate along line EF in Figure 3 are next resisted by the roof diaphragm.

The diaphragm acts like a long deep beam which transfers these forces to the sidewall shear wall elements. These are the elements that carry the applied loads into the ground. First, however, the forces from the diaphragm have to be transferred into the shear wall elements (Figure 3a). This force loads the fasteners in a direction parallel to the top plate grain direction.

The shear wall elements are often modeled as solid walls (Figure 4). Yet the problem builders face is that customers do not want solid walls – they want doors and windows in the walls.

Because of this, Figure 5 is a more accurate engineering representation of a typical wall. The openings mean that each shear wall segment must be designed as a small shear wall and the total of all the segments must have the capacity to carry the total applied loads into the foundation.

The base of the shear wall segments should be fastened with the perimeter anchor bolts that are seen on the end walls (Figure 5a). These connections

FIGURE 3 **Roof diaphragm provides resistance to lateral loads**

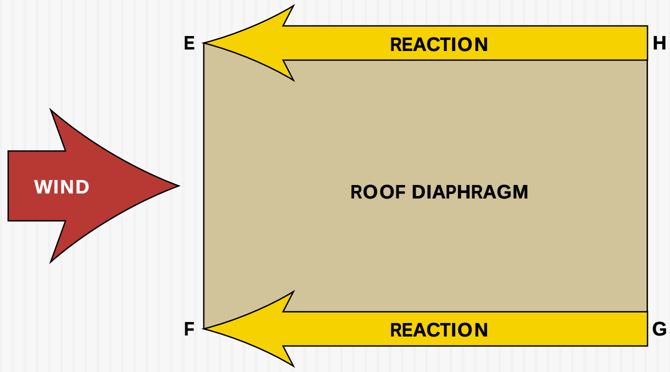


FIGURE 3a **Roof to wall connections – fasteners must be able to transfer forces between roof and walls**

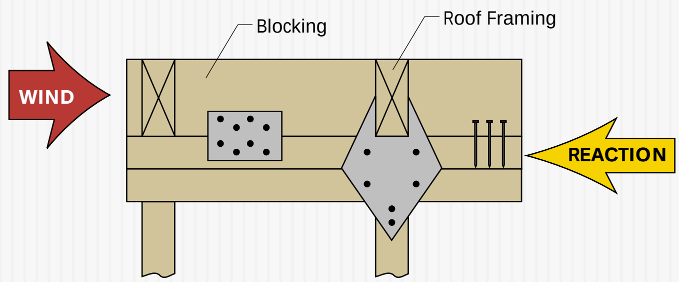
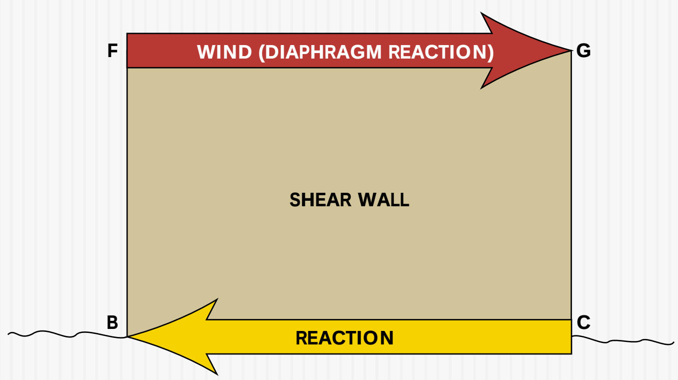


FIGURE 4 **Shear wall reaction to lateral loads**



transfer the base shear into the foundation. In this case bolts are being used to transfer the forces as shown, although framing anchors are available for the same purpose. The bolts load the bottom plate in a direction parallel to the grain.

These anchor bolts restrain the shear segments from sliding, and develops the overturning forces discussed earlier (Figure 6).

These overturning forces are not considered a part of the uplift force of the structure. Unfortunately, these overturning forces are not distributed evenly around the structure. They “show up” as very large concentrated loads at the edges of shear walls. Because these forces have the potential for being very large (1,500-15,000 lbs.), nails or even the perimeter anchor bolts previously discussed do not have the capacity to deal with such loads. For this reason, holddown anchors were developed (Figure 6a).

At shear walls as well as at all other elements and connections between elements forces in all 3 directions must be accommodated. In addition, fasteners must have *sufficient capacity* in all directions, which means that more connections will be needed when building for lateral loads to ensure adequite strength under all loads.

Understanding the forces associated with high wind and earthquake zones and adopting the associated concepts, recommended fasteners and construction techniques are essential to building a safe and long-lasting structure. Following APA guidelines for shear wall and diaphragm construction and using APA Rated Sheathing further ensure quality and superior performance under extreme conditions.

FIGURE 5 **Reaction of segments in shear wall with openings**

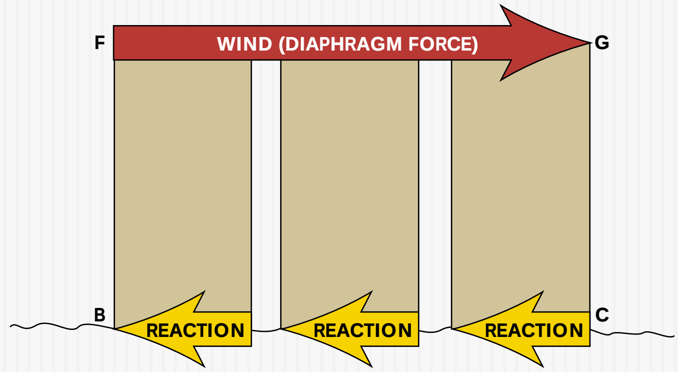


FIGURE 5a **Shear wall anchor bolts – transfer shear forces into foundation**

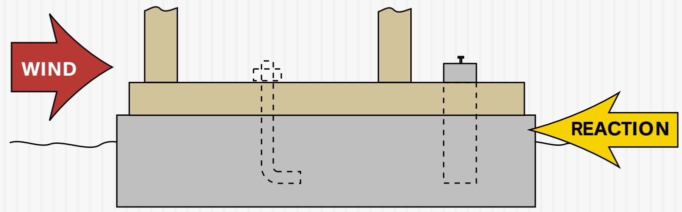


FIGURE 6 **Overturning forces**

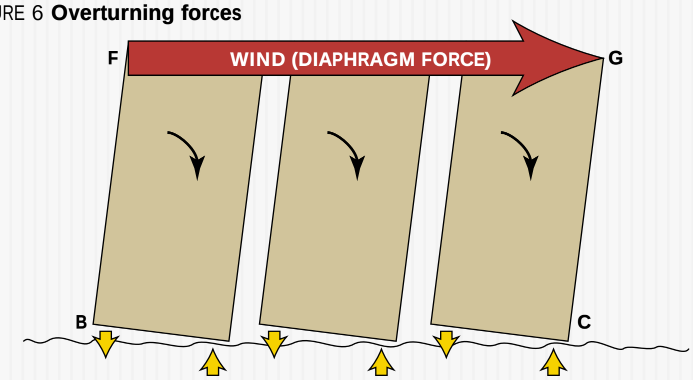
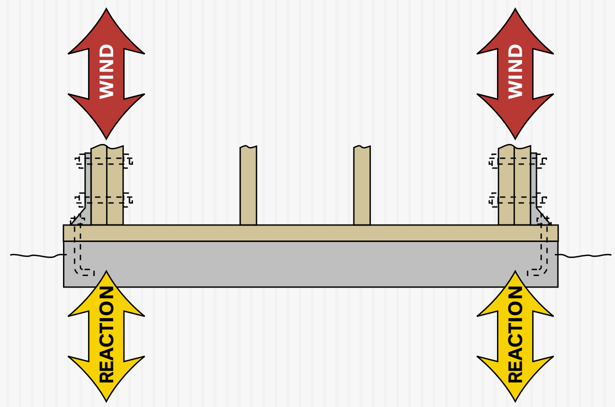


FIGURE 6a **Holddown anchors – transfer overturning forces into foundation**



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WESTERN REGION

7011 So. 19th St. ▪ P.O. Box 11700
Tacoma, Washington 98411-0700
(253) 565-6600 ▪ Fax: (253) 565-7265

EASTERN REGION

2130 Barrett Park Drive, Suite 102
Kennesaw, Georgia 30144-3681
(770) 427-9371 ▪ Fax: (770) 423-1703

U.S. HEADQUARTERS AND INTERNATIONAL MARKETING DIVISION

7011 So. 19th St. ▪ P.O. Box 11700
Tacoma, Washington 98411-0700
(253) 565-6600 ▪ Fax: (253) 565-7265

Web Address:
@
www.apawood.org

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