

# INTRODUCTION TO LATERAL DESIGN



# WOOD

## The Miracle Material™



Wood is the right choice for a host of construction applications. It is the earth's natural, energy efficient and renewable building material.

**Engineered wood is a better use of wood.** The miracle in today's wood products is that they make more efficient use of the wood fiber resource to make stronger plywood, oriented strand board, I-joists, glued laminated timbers, and laminated veneer lumber. That's good for the environment, and good for designers seeking strong, efficient, and striking building design.

### A few facts about wood.

- **We're not running out of trees.** One-third of the United States land base – 731 million acres – is covered by forests. About two-thirds of that 731 million acres is suitable for repeated planting and harvesting of timber. But only about half of the land suitable for growing timber is open to logging. Most of that harvestable acreage also is open to other uses, such as camping, hiking, and hunting. Forests fully cover one-half of Canada's land mass. Of this forestland, nearly half is considered productive, or capable of producing timber on a sustained yield basis. Canada has the highest per capita accumulation of protected natural areas in the world – areas including national and provincial parks.



- **We're growing more wood every day.** American landowners plant more than two billion trees every year. In addition, millions of trees seed naturally. The forest products industry, which comprises about 15 percent of forestland ownership, is responsible for 41 percent of replanted forest acreage. That works out to more than one billion trees a year, or about three million trees planted every day. This high rate of replanting accounts for the fact that each year, 27 percent more timber is grown than is harvested. Canada's replanting record shows a fourfold increase in the number of trees planted between 1975 and 1990.

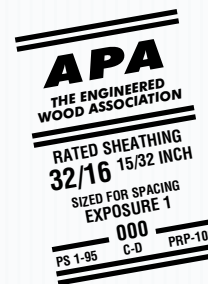
- **Manufacturing wood is energy efficient.** Wood products made up 47 percent of all industrial raw materials manufactured in the United States, yet consumed only 4 percent of the energy needed to manufacture all industrial raw materials, according to a 1987 study.

Material	Percent of Production	Percent of Energy Use
Wood	47	4
Steel	23	48
Aluminum	2	8



- **Good news for a healthy planet.** For every ton of wood grown, a young forest produces 1.07 tons of oxygen and absorbs 1.47 tons of carbon dioxide.

Wood, the miracle material for the environment, for design, and for strong, lasting construction.



**NOTICE:**  
The recommendations in this guide apply only to panels that bear the APA trademark. Only panels bearing the APA trademark are subject to the Association's quality auditing program.

**T**his publication describes how wood framed buildings can be designed to withstand lateral loads such as those caused by high winds (hurricanes) or seismic forces (earthquakes). When building or designing in areas with seismic and high wind loads, it is essential to understand how lateral loads affect structures. Also important is knowledge of how construction detailing and connections affect the ultimate performance of the building.

The elements of a wood-framed building that enable it to withstand earthquake and hurricane forces are its shear walls and diaphragms. Wood-framed construction systems rely completely on the correct and adequate design and installation of these and all other components of the structure, including framing, wood structural panel sheathing and connections.

Wood-frame construction makes it easy for building professionals to design and construct safe, strong buildings that meet code requirements while fulfilling lateral design criteria.

Wood's inherent characteristics make it an ideal material for shear wall and diaphragm design. Its light weight results in less force due to inertia during an earthquake, and less force means less damage. Wood's flexibility allows the building to better absorb and resist the forces found in both earthquakes and high winds. Finally, wood structural panels provide a cost effective means of meeting design requirements for shear walls and diaphragms.

If the information you need to use APA trade-marked wood structural panels in shear wall or diaphragm applications is not found in this publication, or if you need assistance, contact APA at the number listed on the back cover of this guide.

## CONTENTS

<b>Vertical vs. Lateral Loads – a Primer</b> . . . . .	4
Load Path . . . . .	4
Lateral Design Terminology . . . . .	5
Differences Between Wind and Seismic Loads . . . . .	6
What Holds a Building Together? . . . . .	7
Limitations of Toenails . . . . .	8
<b>Shear Walls and Diaphragms</b> . . . . .	8
Engineered versus Prescriptive Requirements . . . . .	9
Bracing versus Shear Wall . . . . .	9
What is Wall Bracing? . . . . .	10
Comparative Tests of Wall Sheathing Products Under Cyclic Loading . . . . .	10
<b>Diaphragms</b> . . . . .	11
Using Wood Structural Panels to Design Diaphragms . . . . .	11
How is a diaphragm designed for a sloped roof? . . . . .	11
What are blocked and unblocked diaphragms? . . . . .	11
Can a continuous ridge vent be used in conjunction with a roof diaphragm? . . . . .	12
Using the Diaphragm Table . . . . .	12
<b>Shear Walls</b> . . . . .	14
Using Wood Structural Panels in Shear Walls . . . . .	14
How does a shear wall differ from a diaphragm? . . . . .	14
What is a shear wall segment? . . . . .	14
Can plywood siding be used as a shear wall? . . . . .	14
What is base shear? . . . . .	15
What is overturning? . . . . .	15
Using the Shear Wall Tables . . . . .	15
<i>Becoming a Lateral Design Pro: Tips to Make You a Master of the Tables</i> . . . . .	17
<b>Other Considerations</b> . . . . .	17
Drag Struts . . . . .	17
Diaphragm and Shear Wall Chords . . . . .	18
Perforated Shear Walls (Type II Shear Walls) . . . . .	18
Lateral Design – The Next Step . . . . .	18
<b>Additional Information</b> . . . . .	19
About APA – The Engineered Wood Association . . . . .	19

## **VERTICAL VS. LATERAL LOADS – A PRIMER**

Any building, regardless of size or location, must be designed to safely resist the structural loads anticipated during its lifetime. These loads can be divided into two categories – vertical loads and lateral loads.

**Vertical loads** are loads acting in the “up and down” direction. These loads are the obvious ones; the weight of the building itself (dead load), the weight of everything in the building (live load) and variable loads such as those from snow. Because these loads are easy to understand, typical construction practice has evolved into an efficient system that does a good job of accommodating them.

The challenge lies with the “other loads,” the lateral loads. **Lateral loads** are those that act in a direction parallel to the ground. The two major contributors to lateral load are high winds, such as those from a hurricane, and seismic (earthquake) forces. Neither type of load is intuitive and designing for these loads is typically not fully covered at the university level, or well understood outside of a few limited academic and engineering circles.

To further complicate matters, because wind and seismic forces can be felt on the building from any direction, the structure must be designed to withstand lateral loads in two directions at right angles to each other. As a result, three separate load designs must be calculated

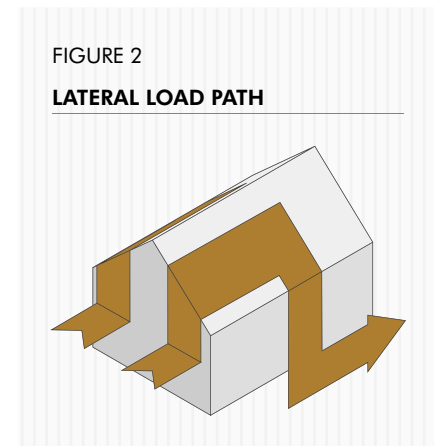
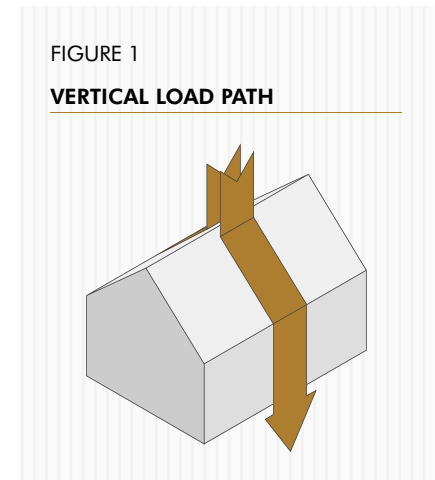
for every building: one vertical load design and two lateral load designs (one for each direction). Then, the load capacity of all major building elements and **every** connection between each element must be calculated to make sure each has the capacity to resist all three loads and transfer lateral and vertical forces between them.

Correct lateral design is essential. A building that has not been specifically designed and built to resist lateral loads will likely collapse when subjected to these forces. This was proven by the massive destruction seen as a result of Hurricane Andrew and the Northridge, California Earthquake. This publication is intended to help building designers avoid such disasters through proper lateral design and detailing.

### **Load Path**

One of the most basic yet important considerations facing building designers is that each individual building element must be designed to carry expected loads. In addition, these loads must be transferred through the rest of the structure into the foundation. Finally, every connection between the elements of the structure must be designed so that the applied loads can be transferred from one element to the next until they reach the ground. This transfer of forces through the structure is called the **load path**.

Understanding a **vertical load path** is quite straightforward. Vertical loads act upwards or downwards on the horizontal elements of the structure – the roof and floors. The roof and floors transfer these loads to the load-bearing walls below and



into the foundation. From the foundation, the load is then transferred into the ground. Therefore, the load path for vertical loads is: from the roof or floor to the supporting walls, through the floors below, to the foundation and finally to the ground. Vertical load transfer is simplified because of the way elements are “stacked” on top of each other in conventional framing. No such advantage exists for lateral load design.

The **lateral load path** is less intuitive but the rules remain the same. The

major elements of a wood-framed building that enable it to withstand lateral forces are **shear walls** and **diaphragms**. These elements must be designed to resist the lateral loads applied, and connections between elements must be strong enough to transfer the loads between elements.

While the load path for wind and earthquake forces varies slightly at the beginning, it is basically the same for all lateral loads. The lateral load is either transferred *into* the roof element (when wind pushes against the walls perpendicular to the wind), or it originates directly *in* the roof element (as would happen during an earthquake). The load is transferred through the roof diaphragm and from the diaphragm by fasteners or framing anchors into the top of the walls that run *parallel* to the direction of the load. This force is then transferred down through the shear walls (and, in the case of a seismic event, added to the force generated within the parallel wall), then into and through the floor below via fasteners or framing anchors. At this point, the force from the roof and walls above is added to the force in the floor diaphragm below and all are transferred, again by fasteners or framing anchors, to the top of the walls parallel to the load below. This process is repeated through successive floors until the loads are transferred into the foundation and from there into the ground.

Therefore, the general lateral load path is from the roof or floor into the walls *parallel to the force*, to the foundation and into the ground. *Remember that this load path is then repeated with the force acting at 90 degrees to the first one.*

## **Lateral Design Terminology**

**Load Path** – the path taken by a force acting on a building. Loads are transferred by the elements in the building and by the connections between those elements into the foundation.

**Diaphragm** – a flat structural unit acting like a deep, thin beam. The term is usually applied to roofs and floors designed to withstand lateral loads. Diaphragms are commonly created by installing wood structural panels over roof or floor supports.

**Shear Wall** – a vertical, cantilevered diaphragm that is constructed to resist lateral shear loads by fastening wood structural panels over wall framing.

**Chord** – the edge members of a diaphragm, typically the joists, ledgers, truss elements, double top plates, etc.

**Box-type Structure** – when diaphragms and shear walls are used in the lateral design of a building, the structural system is called a “box system.”

**Wall Bracing** – a building element that resists lateral loads under low load situations; the configuration and connections are prescribed by the building codes for light framed wood structures.

**Blocked Diaphragm** – a diaphragm in which all panel edges occur over and are nailed to common framing; the additional nailing provides a greater number of fasteners available to transfer shear from one panel to another, thus increasing the overall shear capacity and rigidity or stiffness of the diaphragm.

**Unblocked Diaphragm** – a diaphragm in which only the 4-foot-wide panel ends occur over and are nailed to common framing; this is the most common type of diaphragm used in standard residential construction.

**Shear Wall Segment** – a portion of the shear wall that runs from the diaphragm above to the diaphragm/foundation below; also known as “full-height segments,” shear wall segments occur between openings (such as windows or doors) in the shear wall.

**Base Shear** – the reaction at the base of a wall or structure due to an applied lateral load, a “sliding force.”

**Overturning** – what happens when a lateral force acts on a wall or structure and the wall is restrained from sliding; a “tip-over” or overturning force results.

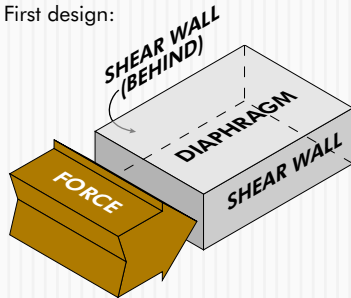
**Drag Strut** – a structural building component that distributes the diaphragm shear from one shear-resisting element to another; typically served by the double top plate.

**Perforated Shear Wall** – a shear wall containing door and window openings that is treated as a single shear wall with a slightly lower capacity than that of a similar full-height shear wall segment.

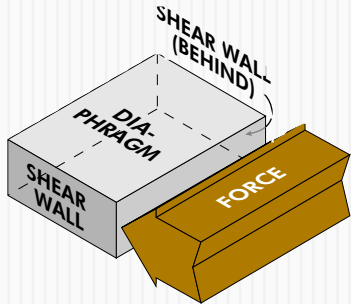
FIGURE 3

**LATERAL LOAD ANALYSIS MUST BE CONDUCTED ALONG BOTH AXES OF STRUCTURE**

First design:



and then design:



Designs based on both lateral load paths must be completed and the elements and inter-element connections designed to resist all applicable vertical and lateral loads. (See Figure 3.)

**Differences Between Wind and Seismic Loads**

At first glance, hurricanes and earthquakes seem to have little in common. But from a building design point of view, they affect structures in a similar manner.

*Seismic forces* are generated by the shaking of the building during an earthquake. The shaking motion causes the structure's mass to be accelerated back and forth, and up and down. This acceleration causes a force to develop within the structure in locations where the structure's mass is the largest. This is at the roof, floor and wall lines parallel to

FIGURE 4

**SEISMIC FORCES ACTING ON MASS**

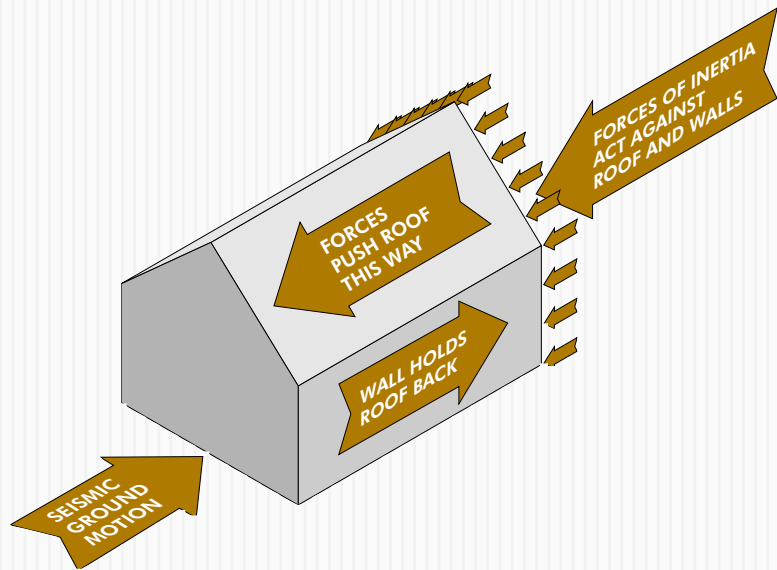
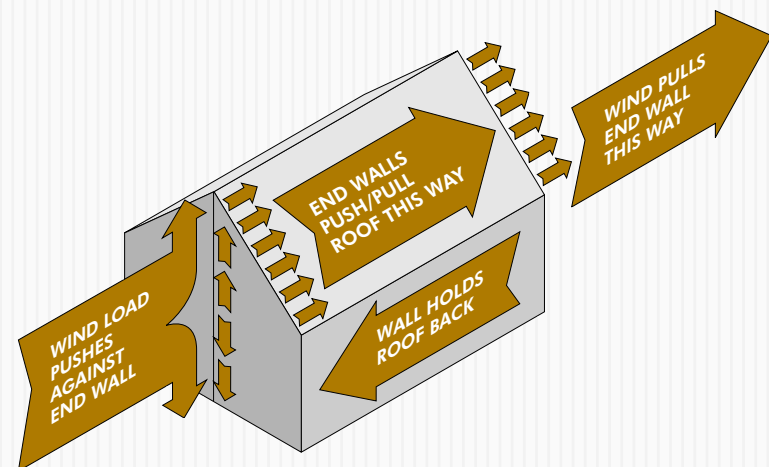


FIGURE 5

**WIND FORCES ACTING ON AREA**



the earthquake forces. Thus, the design loads calculated are applied at these points in the resulting building design.

*Wind forces*, on the other hand, act against the sides of the building, like the

sail on a boat. The forces act over the entire building's cross section. A large percentage of the load is transferred up into the roof/floor and the rest down into the foundation.



## Design Considerations

Earthquakes and hurricanes both have vertical and horizontal force components. Therefore, the structure must be designed for the component acting along *both* horizontal axes, as well as for the vertical component. From a design perspective, once the forces along all three axes of the structure have been determined, the actual building design proceeds identically to accommodate both wind and seismic loads.

The actual determination of the design loads is covered in all of the major model building codes. Seismic loads are computed by considering the:

- Structural type and location of the building
- Importance factor of the building<sup>(1)</sup>
- Soil type under the foundation
- Building geometry
- Actual mass of the structure

Wind loads are also computed after considering a number of factors, including the:

- Orientation of the building with respect to the wind
- Building size and shape
- Design wind speed
- Cover provided by surrounding structures and other terrain features
- Roof slope
- Porosity of the building envelope
- Importance factor of the building<sup>(1)</sup>

## What Holds a Building Together?

The whole idea of engineering a structure is to insure that the building provides an acceptable level of structural integrity so that life-safety is assured during an earthquake or hurricane and structural damage is minimized.

How is this accomplished? What holds the building together? **Connections** are key to the structural integrity of any building.

Light-framed wood structures are known as **box-type structures**. A simple analogy of this type of structure is the common corrugated cardboard box (hence the name “box-type” structure).

The corrugations in the box’s sides are oriented vertically and consequently have a high vertical load carrying capacity. This is similar to the orientation of studs in a light-framed wood wall. Each of the wall elements in the box (and in the wood-framed structure sheathed with wood structural panels) is rigid in terms of racking resistance. In other words, it is extremely hard to force a rectangular side of the cardboard box “out of square.”

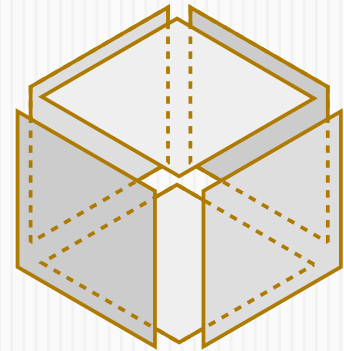
The corrugations in the top and bottom of the box run side to side, thus distributing vertical loads applied to the top or bottom of the box to the sides. In the roof and floors of box-type structures, vertical loads are similarly transferred through the floor and roof trusses or joists into the walls of the structure. Like the sides of the box and walls of a wood framed building, roof and floor elements are also extremely difficult to force “out of square.”

With all of these very admirable physical properties, why is a cardboard box so flimsy until it is assembled? It is only when all of the edges are taped together that a box gains its true potential strength and ability to withstand lateral and vertical loads. The tape is what makes the box work.

Similarly, in a box-type structure, it is the inter-element connections that “tape” the sides together. These connections

FIGURE 6

## PRINCIPLES OF A BOX-TYPE STRUCTURE



All edges of each element must be attached to all edges of adjacent elements to achieve structural rigidity.

allow the forces acting on one element to flow into the adjacent element, progressing through the structure until the forces reach the ground.

This flow of forces completes the load path and provides the property protection and life safety for which the building was designed. The overall strength of a building is a function of the strength of the individual building elements – the walls, roof, floor and foundation – and how those key components are tied together. **Properly designed, detailed and executed connections are key.**

(1) Structures that must be available to provide emergency services after a catastrophe (hospitals, law enforcement, fire fighting facilities and schools) are designed with a greater “factor of safety” to insure their survivability. This is accomplished by assigning such structures a larger “importance factor” during design.

## Limitations of Toenails

When connecting diaphragms or shear walls together, avoid using toenails – they are not the best connection choice available.

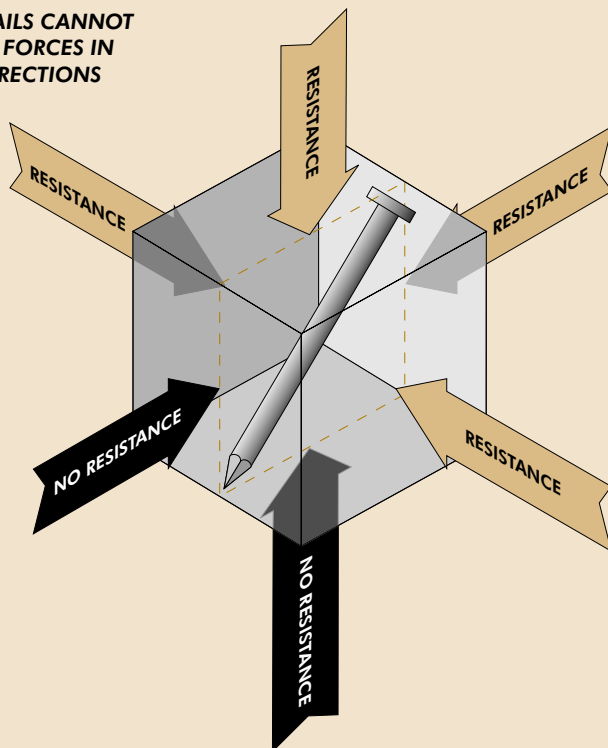
Every structure in a high seismic or hurricane region is subject to loads in all three orthogonal directions, that is, vertical loads (both down and up), as well as loads along both horizontal axes of the structure (loads parallel **and** perpendicular to the plane of the wall). This means that at every joint between elements, roof to end wall, for example, there will be forces trying to pull these elements apart in all three directions. Connections are key to the structural integrity of the building.

In a roof diaphragm-to-shear wall connection, there is a vertical load trying to lift the roof away from the wall (wind uplift or vertical seismic component). There also exists a component of both high wind and seismic forces that tries to slide the roof in a direction parallel to the axis of the wall. In addition, a force is trying to push the wall into or away from the roof diaphragm in a direction perpendicular to the wall. Because these forces are coming from a variety of directions, toenails used by themselves are often inadequate for the following reasons:

- Toenails are good at resisting loads only in certain directions, such as loads perpendicular to the plane of the nail, or “sideways” in relation to the nail.
- Due to the cyclic nature of earthquake and hurricane loads, direction of the load “cycles” back and forth. Cyclic loads in the other directions put the nails in withdrawal half of the time. Nails should never be used in withdrawal.

It is usually necessary to supplement connection details when toenails are used to transfer lateral loads, and often desirable to completely eliminate their use by using a properly designed framing anchor. Framing anchor catalogs give the capacities of their products in all 3 directions as appropriate, for just this reason.

### TOENAILS CANNOT RESIST FORCES IN ALL DIRECTIONS



## SHEAR WALLS AND DIAPHRAGMS

Wind and seismic forces are resisted by **shear walls** that are composed of wood structural sheathing fastened to wood framing, properly connected to the foundation below and the roof above. Similarly, the installation of wood structural panels over a roof or floor supports creates a **diaphragm**, a flat structural unit that acts like a deep, thin beam that resists lateral forces.

Shear walls and diaphragms are building elements necessary for proper lateral design. Aside from the fact that a shear wall is vertical and the diaphragm is horizontal (or nearly horizontal), they are essentially the same kind of structural element. A diaphragm is designed as a simply supported beam while the shear wall is designed like a vertical, cantilevered diaphragm.

A diaphragm acts in a manner similar to a deep I-beam or girder, where the panels act as a “web” resisting shear, while the diaphragm edge members perform the function of flanges,” resisting bending stresses. These edge members are commonly called **chords** in diaphragm design, and may be joists, ledgers, double top plates, etc.



## Engineered versus Prescriptive Requirements

Current model building codes allow the designer to use either of two methods to design light frame wood structures.

Both are appropriate for detached one and two family dwellings as well as many other wood structures. These two methods are by the use of **engineering design** or **prescriptive** requirements.

Chapter 16 of the current editions of all three major model building codes and the International Building Code is the chapter that provides the information required to **engineer** a structure – the design-based requirements. This chapter provides all of the vertical and horizontal design loads (gravity, snow, wind, seismic, impact, construction, live and dead loads, etc.) that must be considered when doing an engineering design of *any type* of structure covered by the building codes.

This chapter provides no guidance on how to actually build the structure. It just provides the loads on the structure. This data must be interpreted by a designer or engineer whose responsibility it is to provide all of the details necessary to resist the applied loads and build the structure.

The wood chapter of each of these building codes (Chapter 23) contains **prescriptive requirements** for the design of wood structures. Prescriptive requirements provide a “cookbook” method for the design of wood structures within certain limitations. They tell the designer

what size and grade lumber to use for different applications, what anchor bolt spacing to use, what size joists to use for various floor spans, the fastening schedule for all applications, etc. Because prescriptive requirements ignore specific factors such as the actual geometry of the structure, actual loads seen by the structure and their location, this design method is limited for use in locations with low wind and minimal risk of seismic activity.

## Bracing versus Shear Walls

The design method chosen, engineered or prescriptive, will determine whether shear walls or wall bracing are used to provide lateral bracing and resistance in the structure.

In the process of **designing** a “box-type” structure, the engineer/designer will find that he or she must provide a number of vertical wall elements designed to resist the horizontal forces acting on the building (earthquake, wind or both). The elements used in a box-type structure to resist lateral loads are **shear walls**. These shear walls also act as interior and exterior walls, load bearing and non-load bearing walls required to meet the architectural goals of the building as well as the requirements of other design loads.

While shear walls may look similar to other walls, they often contain a number of important differences, including:

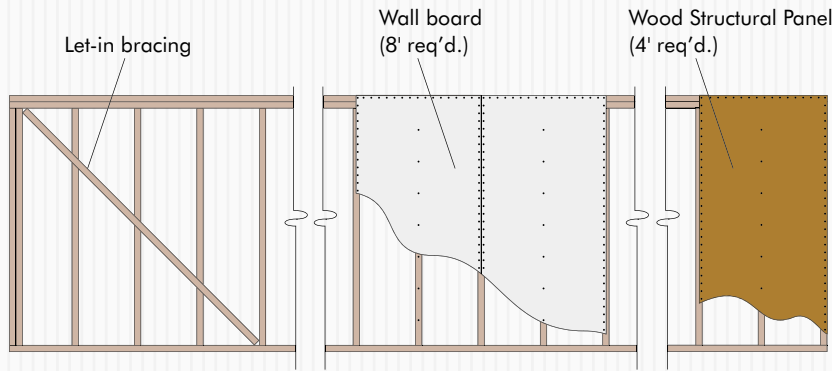
- Additional base shear anchor bolts in the bottom plate (the size and number may be different from the prescriptive requirements of the code)
- Hold-down anchors at each end of the shear wall

- Tighter-than-conventional nailing of the sheathing/siding
- Thicker-than-conventional sheathing/siding
- Different framing grades, species and sizes
- Limitations on the placement of the shear wall segments (e.g., shear walls on upper floors must be placed directly over shear walls below)
- Special fastening requirements at the top of the shear wall elements to insure load transfer from the roof/floor diaphragm into the shear wall

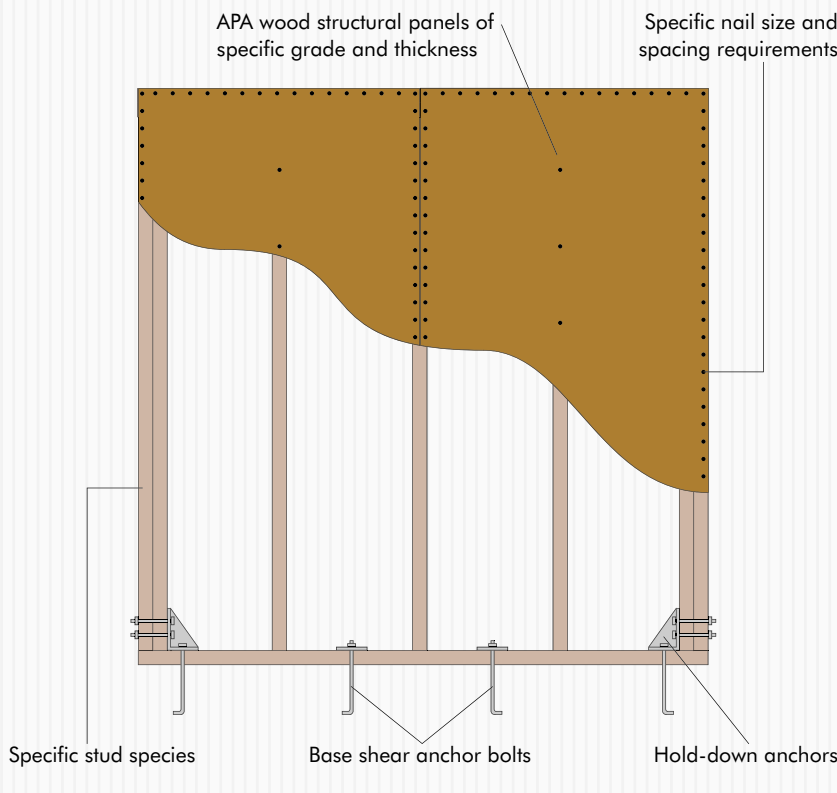
When the building is designed using **prescriptive requirements**, lateral forces are resisted by **wall bracing** instead of by shear walls. This wall bracing must be placed at prescribed locations throughout the structure: e.g., “Each end and not more than 25 feet on center” (taken from Table 2308.9.3(1) of the 2000 International Building Code). While these bracing panels serve the same function as the engineered shear wall – provide resistance to the lateral forces acting on the structure – they have few elements in common with the shear walls described above. Their lack of detailing severely limits the strength and stiffness of the wall bracing when compared with an engineered shear wall. For this reason, wall bracing is relegated to low-load situations.

FIGURE 7

**SHEAR RESISTING ELEMENTS  
PRESCRIPTIVE CORNER BRACING/WALL BRACING**



**ENGINEERED SHEAR WALLS**



**What is Wall Bracing?**

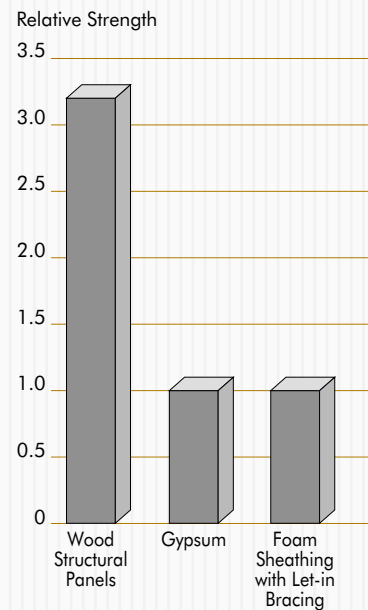
The codes give various options. Most commonly used: one “unit” of wall bracing could be 4 lineal feet of studs sheathed with wood structural panels, 8 lineal feet of studs sheathed with gypsum board on one side, 8 lineal feet of wall containing a let-in brace at 45 degrees (limited to single story or second story of a two story building), etc.

FIGURE 8

**COMPARATIVE TESTS OF WALL SHEATHING PRODUCTS UNDER CYCLIC LOADING**

In recent tests by APA – The Engineered Wood Association, walls fully sheathed with plywood or OSB were three times stronger than walls constructed with gypsum wall sheathing or let-in bracing.

The comparative wall sheathing tests, part of an ongoing research program by APA, were designed to simulate the dynamic effects of seismic events. The tests involved 8 x 8 ft walls constructed according to the bracing provisions and nail schedules of the major model building codes.



## DIAPHRAGMS

### Using Wood Structural Panels to Design Diaphragms

A discussion of diaphragm design invariably raises a number of commonly asked questions:

#### How is a Diaphragm Designed for a Sloped Roof?

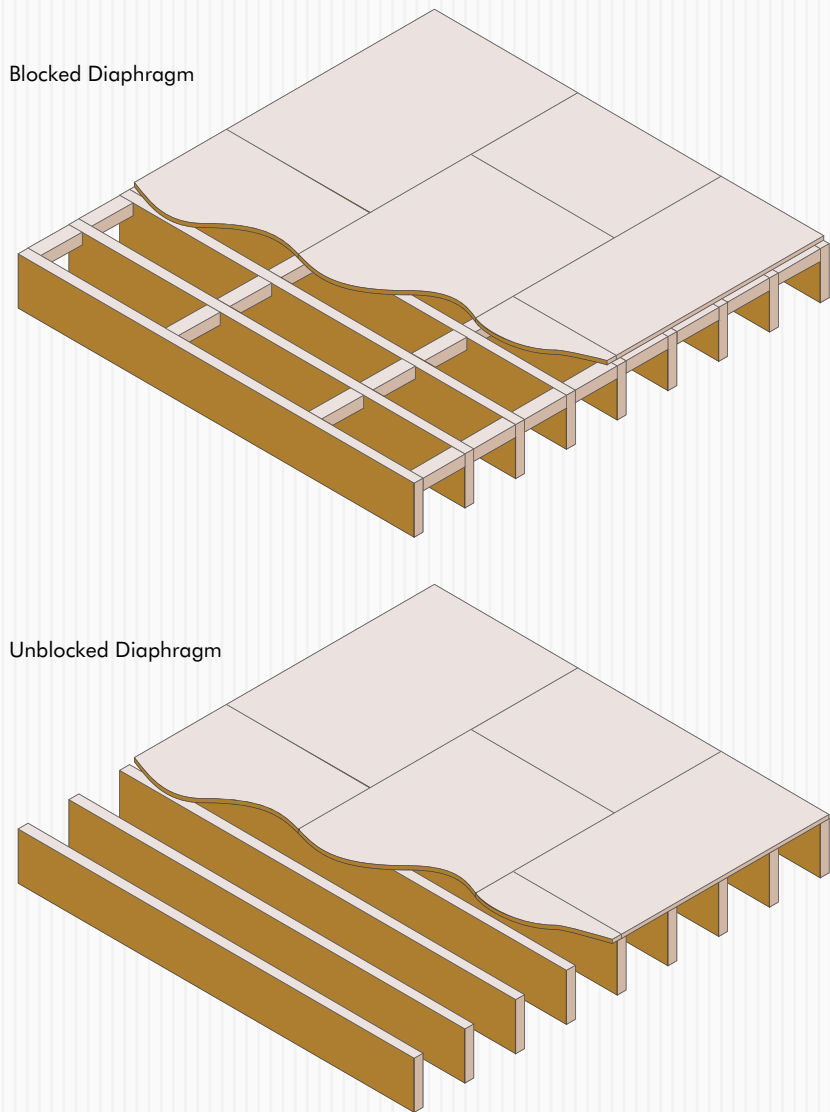
Lateral load design examples are almost always modeled with flat roof diaphragms. This is done because it is easier to visualize the load path through a simple box than through a complicated architectural exercise in multiple, intersecting roof lines and unusual building shapes. Regardless of the shape of the structure or pitch of the roof, buildings can be broken down into rectangular segments and each segment analyzed as if it had a flat roof.

Once the load on the roof diaphragm is determined, the design of the roof diaphragm is conducted on the plan view (or vertical projection) of the diaphragm. After the diaphragm material, thickness, fastener type and spacing has been sized and selected for the “plan view,” it must be used over the entire roof diaphragm, regardless of the actual angle of the roof.

#### What are Blocked and Unblocked Diaphragms?

Diaphragms vary considerably in load-carrying capacity, depending on whether they are “blocked” or “unblocked.” A **blocked diaphragm** is one in which all four panel edges occur over and are nailed to common framing. This additional nailing provides a greater number of fasteners available to transfer shear from one panel to another, thus increasing the overall shear capacity and rigidity or stiffness of the diaphragm.

FIGURE 9  
BLOCKED AND UNBLOCKED DIAPHRAGMS



In an **unblocked diaphragm**, only the 4-foot-wide panel ends occur over and are nailed to common framing. This is the most common type of diaphragm used in standard residential construction. Loads are generally low enough that the added expense of blocking unsupported edges is not required.

As there are fewer nails available to transfer shear from one panel to the next, unblocked diaphragms have lower allowable capacities and are less stiff than blocked diaphragms.

### Can a Continuous Ridge Vent be used in Conjunction with a Roof Diaphragm?

If the roof is designed as an unblocked diaphragm, continuous ridge vents can be used. This is because with an unblocked diaphragm, there is no requirement for a connection to be made between unsupported edges of adjacent panels.

With a blocked diaphragm, the use of a continuous ridge vent is slightly more complicated because all edges of all adjacent panels must occur over and be attached to common framing. This is as true for the ridge as it is for panels occurring in a common plane. In many cases, the connection at the ridge can be detailed, however, to accommodate at least partial ridge venting. This can be done by placing blocking in alternating spaces between the rafters or joists. At the location where there is blocking, the

required nail spacing shall be halved, so that twice as many nails are present to make this connection in every other space. This can be done when the normal blocked diaphragm nail spacing is either 4 or 6 inches on center. If the nailing into the blocking after doubling is at 2-1/2 inches on center or less, the same additional framing-width requirements given in the diaphragm and shear wall tables shall apply. Fortunately, the diaphragm nailing requirements in buildings of a size where pitched roofs are suitable are generally small enough to be accommodated by this method.

### Using the Diaphragm Table

#### Example One:

**Given:** Residential roof diaphragm, trussed roof, unblocked diaphragm required, diaphragm capacity required equals 180 plf, load orientation unknown.

**Solution:** Using Table 1, refer to the “Unblocked Diaphragm” area of the table. As orientation is unknown, use the “All other configurations...” column, since these values will be conservative. Check “APA RATED SHEATHING...” rows first because Structural I may not be readily available in all areas. Similarly, check only rows with 2-inch minimum nominal framing width, as the roof framing is made up of trusses. From the table, see that 8d nails with 15/32-inch sheathing over 2x framing yields a capacity of 180 plf with the standard 6 and 12 nail spacing. As 180 plf is equal to the required 180 plf capacity, this selection is OK for use.

#### Example Two:

**Given:** Commercial roof diaphragm, trussed roof, diaphragm capacity required equals 350 plf with a Case I orientation.

**Solution:** Using Table 1, refer to the “Unblocked Diaphragm” area of the table first. You will find that no solution is possible. Next, check the “Blocked Diaphragm” area of the table. Check “APA RATED SHEATHING...” rows first. Similarly, check only rows with 2-inch minimum nominal framing width as the framing is made up of trusses. From the table, see that 8d nails with 15/32-inch Sheathing over 2x framing yields a capacity of 360 plf. Nails must be placed at 4 inches on center at all diaphragm boundaries and at 6 inches on center at all other panel edges. As 360 plf is greater than 350 plf, this selection is OK for use.

FIGURE 10

### ACCOMMODATING RIDGE VENTS WITH BLOCKED DIAPHRAGMS

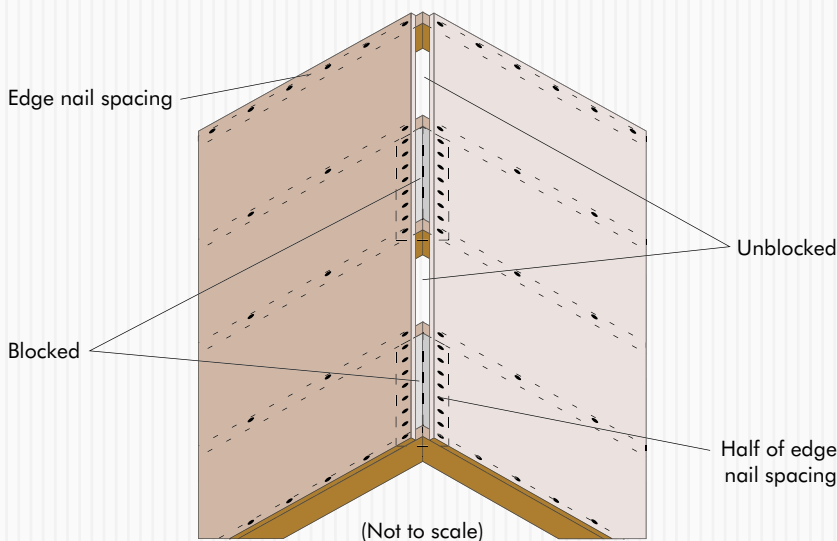


TABLE 1

**DIAPHRAGMS: RECOMMENDED SHEAR (POUNDS PER FOOT) FOR HORIZONTAL APA PANEL DIAPHRAGMS WITH FRAMING OF DOUGLAS-FIR, LARCH OR SOUTHERN PINE<sup>(a)</sup> FOR WIND OR SEISMIC LOADING**

Panel Grade	Common Nail Size	Minimum Nail Penetration in Framing (inches)	Minimum Nominal Panel Thickness (inch)	Minimum Nominal Width of Framing Member (inches)	Blocked Diaphragms				Unblocked Diaphragms		
					Nail Spacing (in.) at diaphragm boundaries (all cases), at continuous panel edges parallel to load (Cases 3 & 4), and at all panel edges (Cases 5 & 6) <sup>(b)</sup>				Nails Spaced 6" max. at Supported Edges <sup>(b)</sup>		
					6	4	2-1/2 <sup>(c)</sup>	2 <sup>(c)</sup>	Case 1 (No unblocked edges or continuous joints parallel to load)		All other configurations (Cases 2, 3, 4, 5 & 6)
					Nail Spacing (in.) at other panel edges (Cases 1, 2, 3 & 4)						
6	6	4	3								
APA STRUCTURAL I grades	6d	1-1/4	5/16	2 3	185 210	250 280	375 420	420 475	165 185	125 140	
	8d	1-3/8	3/8	2 3	270 300	360 400	530 600	600 675	240 265	180 200	
	10d <sup>(d)</sup>	1-1/2	15/32	2 3	320 360	425 480	640 720	730 820	285 320	215 240	
APA RATED SHEATHING, APA RATED STURD-I-FLOOR and other APA grades except Species Group 5	6d <sup>(e)</sup>	1-1/4	5/16	2 3	170 190	225 250	335 380	380 430	150 170	110 125	
			3/8	2 3	185 210	250 280	375 420	420 475	165 185	125 140	
	8d	1-3/8	3/8	2 3	240 270	320 360	480 540	545 610	215 240	160 180	
			7/16	2 3	255 285	340 380	505 570	575 645	230 255	170 190	
	10d <sup>(d)</sup>	1-1/2	15/32	2 3	270 300	360 400	530 600	600 675	240 265	180 200	
			19/32	2 3	290 325	385 430	575 650	655 735	255 290	190 215	

(a) For framing of other species: (1) Find specific gravity for species of lumber in the AFPA National Design Specification. (2) Find shear value from table above for nail size for actual grade. (3) Multiply value by the following adjustment factor: Specific Gravity Adjustment Factor = [1 - (0.5 - SG)], where SG = specific gravity of the framing. This adjustment shall not be greater than 1.

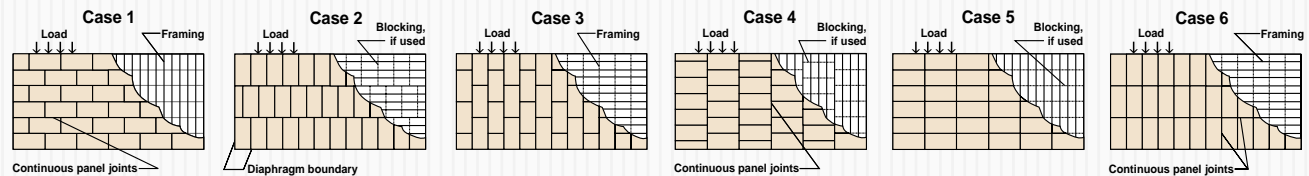
(b) Space nails maximum 12 in. o.c. along intermediate framing members (6 in. o.c. when supports are spaced 48 in. o.c.).

(c) Framing at adjoining panel edges shall be 3-in. nominal or wider, and nails shall be staggered where nails are spaced 2 inches o.c. or 2-1/2 inches o.c.

(d) Framing at adjoining panel edges shall be 3-in. nominal or wider, and nails shall be staggered where 10d nails having penetration into framing of more than 1-5/8 inches are spaced 3 inches o.c.

(e) 8d is recommended minimum for roofs due to negative pressures of high winds.

**Notes:** Design for diaphragm stresses depends on direction of continuous panel joints with reference to load, not on direction of long dimension of sheet. Continuous framing may be in either direction for blocked diaphragms.



## SHEAR WALLS

### Using Wood Structural Panels in Shear Walls

Following are questions that are commonly raised about shear walls:

#### How Does a Shear Wall Differ from a Diaphragm?

They are essentially the same kind of structural element – both comprised of structural lumber components used to carry the vertical loads, splice the wood structural panels together and hold them in place. The shear load is carried through the wood structural panel sheathing to adjacent sheathing panels through the lumber framing. In essence, the shear wall table is really just a “special case” diaphragm table. In fact, the diaphragm table is sometimes used to design shear walls.

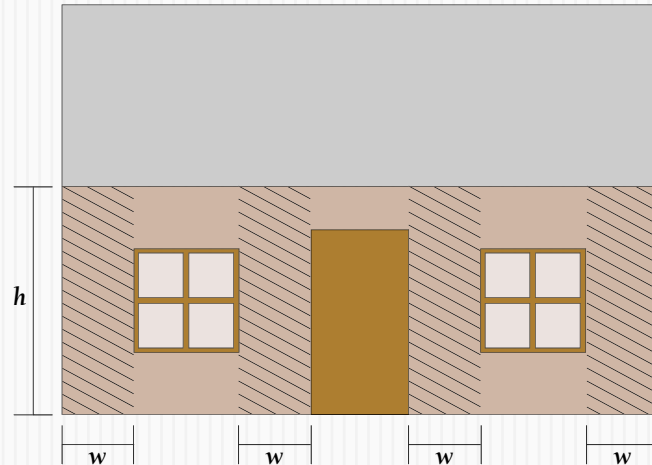
A Shear Wall...	A Diaphragm...
Is vertical	Is horizontal (or nearly so)
Is designed like a cantilevered beam	Is designed as a simply supported beam
Table has only blocked values, because a shear wall is always blocked*	Table has both blocked and unblocked diaphragm values

\*A code requirement.

FIGURE 11

### SHEAR WALL SEGMENT

Local building codes typically stipulate a minimum  $w$  of  $h/3.5$



#### What is a Shear Wall Segment?

A *shear wall segment* in a conventional shear wall is the portion of the shear wall that runs from the diaphragm above (such as a roof) to the diaphragm (floor) or foundation below. Also known as full-height segments, true shear wall segments occur *between* openings (such as windows or doors) in the shear wall. In conventional shear wall design, only the full-height segments may be used to transfer the shear from the diaphragm above to and through the floor below.

Design practice and building codes put further restrictions on the geometry of shear wall segments to insure that minimum height-to-width ratios are maintained to hold building deformations to a level that can be tolerated.

#### Can Plywood Siding be used as a Shear Wall?

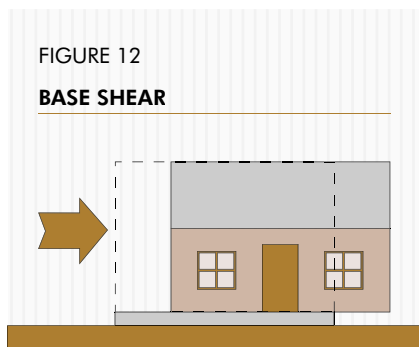
Yes, all three of the major model building codes and the International Building Code recognize the use of APA 303 Plywood Siding (such as T1-11) for use as shear walls. Sidings have the same capacity as Sheathing grade wood structural panels of the same thickness when similarly attached. The thickness of the plywood siding panel *at the point of nailing* is used to determine its capacity.

There are a number of non-plywood siding panels known as APA Rated Siding that have also been recognized for such uses. The actual design information for such products is proprietary and available from the manufacturer.



### What is Base Shear?

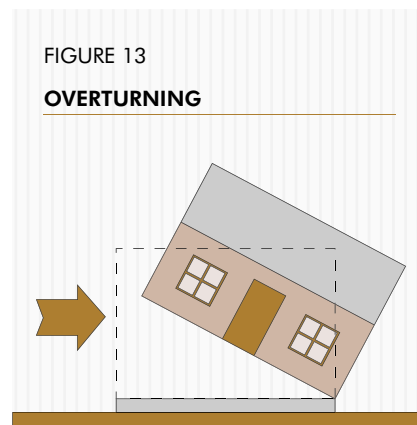
**Base shear** is the force acting at the base of the structure in a direction parallel to the axis of the shear wall. The base shear connection keeps the building from sliding off its foundation. As discussed on page 5, the purpose of a shear wall is to transfer the lateral load acting on the wall from above down through the floor below and on into the foundation. The wood structural panel sheathing on the wall provides the rigidity and strength to accomplish this task. When transferring shear between the second- and first-floor shear walls, the wood structural panel sheathing, if constructed so that all panel edges occur over and are attached to common framing, will provide this shear transfer connection. At the foundation where the wood structural panel shear wall sheathing from above is fastened to the plate below, the base shear transfer is accomplished by bolting the plate down to the foundation. These anchor bolts are also known as base shear anchors.



### What is Overturning?

Once the shear wall is bolted soundly to the foundation with the base shear anchors (and thus prevented from sliding), the force acting on the shear wall at the roof level and second floor level acts in such a way as to overturn the shear wall. The taller the structure, the greater the force. **Overturning** is prevented by anchoring the double studs, 3x\_ or 4x\_ members at each end of each shear wall segment down to the foundation with a tension tie. These ties are called “hold-downs.” The tension ties in shear walls located in floors above the ground floor must be continuous through the lower floor walls and must be ultimately tied into the foundation.

The base shear anchors, previously discussed, are placed to prevent sliding only, and are not intended to hold down the shear wall against overturning. If used for this purpose, the bottom plate will stay in place and the sheathing on the shear wall may “unzip” from the bottom plate as the wall overturns.



### Using the Shear Wall Tables

#### Example One:

**Given:** Commercial building shear wall requiring 5/8-inch gypsum sheathing on outside of building for one-hour fire separation. Required shear wall capacity equals 437 plf.

#### Solution:

Using Table 2, check the “Panels applied over 1/2” or 5/8” gypsum sheathing” area of table. Check “APA RATED SHEATHING...” rows first because Structural I may not be readily available in all areas. From the table, see that 10d nails with a 3 and 12 nail spacing and any thickness of APA Rated Sheathing will provide a capacity of 490 plf provided that the framing at adjoining panel edges is 3-inch nominal or wider. As 490 plf is greater than 437 plf, this selection is OK for use.

TABLE 2

**SHEAR WALLS: RECOMMENDED SHEAR (POUNDS PER FOOT) FOR APA PANEL SHEAR WALLS WITH FRAMING OF DOUGLAS-FIR, LARCH, OR SOUTHERN PINE<sup>(a)</sup> FOR WIND OR SEISMIC LOADING<sup>(b)</sup>**

Panel Grade	Minimum Nominal Panel Thickness (in.)	Minimum Nail Penetration in Framing (in.)	Panels Applied Direct to Framing				Panels Applied Over 1/2" or 5/8" Gypsum Sheathing					
			Nail Size (common or galvanized box)	Nail Spacing at Panel Edges (in.)				Nail Size (common or galvanized box)	Nail Spacing at Panel Edges (in.)			
				6	4	3	2 <sup>(e)</sup>		6	4	3	2 <sup>(e)</sup>
APA STRUCTURAL I grades	5/16	1-1/4	6d	200	300	390	510	8d	200	300	390	510
	3/8			230 <sup>(d)</sup>	360 <sup>(d)</sup>	460 <sup>(d)</sup>	610 <sup>(d)</sup>					
	7/16	1-3/8	8d	255 <sup>(d)</sup>	395 <sup>(d)</sup>	505 <sup>(d)</sup>	670 <sup>(d)</sup>	10d <sup>(f)</sup>	280	430	550	730
	15/32			280	430	550	730					
	15/32	1-1/2	10d <sup>(f)</sup>	340	510	665	870	—	—	—	—	—
APA RATED SHEATHING; APA RATED SIDING <sup>(g)</sup> and other APA grades except species Group 5	5/16 or 1/4 <sup>(c)</sup>			180	270	350	450		180	270	350	450
	3/8	1-1/4	6d	200	300	390	510	8d	200	300	390	510
	3/8			220 <sup>(d)</sup>	320 <sup>(d)</sup>	410 <sup>(d)</sup>	530 <sup>(d)</sup>					
	7/16	1-3/8	8d	240 <sup>(d)</sup>	350 <sup>(d)</sup>	450 <sup>(d)</sup>	585 <sup>(d)</sup>	10d <sup>(f)</sup>	260	380	490	640
	15/32			260	380	490	640					
	15/32			310	460	600	770	—	—	—	—	—
	19/32	1-1/2	10d <sup>(f)</sup>	340	510	665	870	—	—	—	—	—
APA RATED SIDING 303 <sup>(g)</sup> and other APA grades except species Group 5			Nail Size (galvanized casing)					Nail Size (galvanized casing)				
	5/16 <sup>(c)</sup>	1-1/4	6d	140	210	275	360	8d	140	210	275	360
	3/8	1-3/8	8d	160	240	310	410	10d <sup>(f)</sup>	160	240	310	410

(a) For framing of other species: (1) Find specific gravity for species of lumber in the AFPA National Design Specification. (2) For common or galvanized box nails, find shear value from table above for nail size for actual grade. (3) Multiply value by the following adjustment factor: Specific Gravity Adjustment Factor = [1 - (0.5 - SG)], where SG = specific gravity of the framing. This adjustment shall not be greater than 1.

(b) All panel edges backed with 2-inch nominal or wider framing. Install panels either horizontally or vertically. Space nails maximum 6 inches o.c. along intermediate framing members for 3/8-inch and 7/16-inch panels installed on studs spaced 24 inches o.c. For other conditions and panel thicknesses, space nails maximum 12 inches o.c. on intermediate supports.

(c) 3/8-inch or APA RATED SIDING 16 oc is minimum recommended when applied direct to framing as exterior siding.

(d) Shears may be increased to values shown for 15/32-inch sheathing with same nailing provided (1) studs are spaced a maximum of 16 inches o.c., or (2) if panels are applied with long dimension across studs.

(e) Framing at adjoining panel edges shall be 3-inch nominal or wider, and nails shall be staggered where nails are spaced 2 inches o.c.

(f) Framing at adjoining panel edges shall be 3-inch nominal or wider, and nails shall be staggered where 10d nails having penetration into framing of more than 1-5/8 inches are spaced 3 inches o.c.

(g) Values apply to all-veneer plywood APA RATED SIDING panels only. Other APA RATED SIDING panels may also qualify on a proprietary basis. APA RATED SIDING 16 oc plywood may be 1 1/32 inch, 3/8 inch or thicker. Thickness at point of nailing on panel edges governs shear values.

**Typical Layout for Shear Walls**

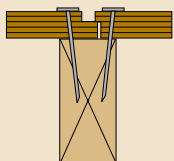


## Becoming a Lateral Design Pro: Tips to Make You a Master of the Tables

Using the diaphragm and shear wall tables is relatively simple. After calculating your required capacity, simply find the recommended design capacities. However, there are tips that can be used in both tables that will give you greater flexibility, permit substitutions and allow more economical designs.

- If a Structural I panel is selected from the tables, note that the same value can be achieved with a non-Structural I panel simply by increasing the thickness 1/8 of an inch. Because Structural I panels may not be readily available in all areas and are often higher in cost than non-Structural I sheathing, this alternative provides design flexibility. The thicker panel will also provide a better nail base and may improve the capacity of the panel for normal loads, and may also be more inexpensive.
- If the capacity of a given panel thickness with a 6 and 12 nail spacing (6" on center at supported panel edges and 12" on center over interior supports) isn't enough, consider a tighter nail spacing (4" or 3" on center) before going with a thicker panel.
- When designing a diaphragm, only block the portion of the diaphragm that needs blocking – those areas where the diaphragm shear exceeds the unblocked diaphragm capacity given for the panel type, thickness, fastener type and spacing. This saves time and labor.
- If a shear wall or diaphragm design load gets high enough to require the use of nail spacings of 2-1/2 inches or less, consider using thicker panels because 3 x framing is typically required at adjoining panel edges for these tight nail spacings. In these cases, thicker panels with a wider nail spacing may be a more cost-effective solution.
- In the shear wall table, the thickness of the panel at the point of nailing determines the panel thickness. Thus, if a 19/32-inch-thick siding panel is to be used as a shear wall and the long panel edges are nailed so that the nail does not go through the shiplapped or grooved area of the panel edge, then the full 19/32-inch thickness of the panel may be used to determine the shear wall capacity. This usually means starting the nails a little farther in from the edge of the panel and slanting them about 10 degrees toward the stud.

### T1-11 nailing



**Note:**  
Nailing of both panel edges along shiplap joints is recommended. The "double nailing" is required when wall segment must meet wall bracing or engineered shear wall requirements.

## OTHER CONSIDERATIONS

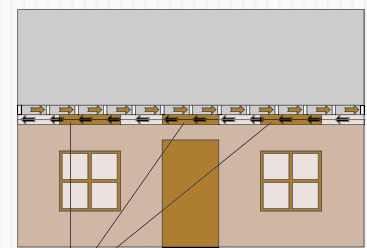
### Drag Struts

As described on page 4, the load path for a box-type structure goes from the diaphragm into the shear walls running parallel to the direction of the load. Another way to say this is that the diaphragm loads the shear walls that support it. Because the diaphragm acts like a long, deep beam, it loads each of the supporting shear walls evenly along the length of the walls. The problem lies with the fact that seldom is each shear wall solid throughout its full length. Typically, a wall contains windows and doors.

The traditional model used to analyze shear walls only recognizes wall segments that run full height as shear wall segments. This means that at locations with windows or doors, a structural element is needed to distribute the uniform diaphragm shear over the top of the opening into the full height segments adjacent to it. This element is called a **drag strut**.

FIGURE 14

### TOP PLATE DRAG STRUTS



Double top plate acts like a drag strut in these locations (over openings).

Fortunately, in residential construction, the double top plates existing in most stud walls will serve as a drag strut. It may be necessary to detail the double top plate such that no splices occur in critical zones. Or it may be necessary to specify the use of a tension strap at butt joints to transfer these forces.

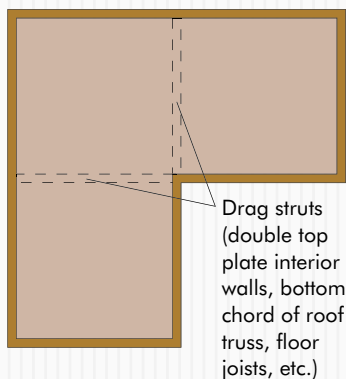
The maximum force seen by drag struts is generally equal to the diaphragm design shear in the direction of the shear wall multiplied by the distance between the shear wall segments.

Drag struts are also used to tie together different parts of an irregularly shaped building:

To simplify design, irregularly shaped buildings (such as “L” or “T” shaped) are typically divided into simple rectangles. When the structure is “reassembled” after the individual designs have been completed, drag struts are used to provide the necessary continuity between these individual segments to insure that the building will act as a whole.

FIGURE 15

**DRAG STRUTS USED TO TIE AN “L” SHAPED BUILDING TOGETHER**



### Diaphragm and Shear Wall Chords

Blocked diaphragms are thought to act like long deep beams. This model assumes that shear forces are accommodated by the wood structural panel web of the “beam” and that moment forces are carried by the tension or compression forces in the flanges or chords of the “beam.” These chord forces are normally assumed to be carried by the double top plate of the supporting perimeter walls. Given the magnitude of the forces involved in most light framed wood construction projects, the double top plate has sufficient capacity to resist the tensile and compressive forces, assuming adequate detailing at the splice locations. The real problem lies in wall lines that make a continuous diaphragm chord impossible.

Because shear walls are little more than blocked, cantilevered diaphragms, they too develop chord forces and require chords. The chords in a shear wall are the double studs that are required at each end of each shear wall. Just as the chords need to be continuous in a diaphragm, the chords in a shear wall also need to maintain their continuity. This is accomplished by the tension ties (hold-downs) that are required at each end of each shear wall and between the chords of stacked shear walls.

### Perforated Shear Walls (Type II Shear Walls)

A considerable amount of research is being done by organizations on the subject of *perforated shear walls* (also known as Type II shear walls). This procedure allows a wall with door and window openings to be treated as a single shear wall with a slightly lower capacity. The advantage of this method is that the entire perforated wall only requires two hold-downs, one at each end. The traditional methodology would have required that the wall be broken into segments, and each segment anchored with a pair of hold-downs. As hold-downs can be costly and difficult to install properly, contractors are generally well disposed to eliminating anchors at the cost of thicker sheathing and additional nailing. The perforated shear wall method has recently been included in the International Building Code and has been in the Standard Building Code for some years.

### Lateral Design – The Next Step

Once familiar with the concepts presented in this publication, the designer can work through the detailed design examples found in *APA Design/Construction Guide: Diaphragms and Shear Walls*, Form L350. This publication can be obtained through your local APA field representative, from APA headquarters in Tacoma, Washington, or from the Association’s web site at [www.apawood.org](http://www.apawood.org).



## ADDITIONAL INFORMATION

### About APA – The Engineered Wood Association

APA – The Engineered Wood Association is a nonprofit trade association whose member mills produce a majority of the structural wood panel products manufactured in North America.

The Association's trademark appears only on products manufactured by member mills and is the manufacturer's assurance that the product conforms to the standard shown on the trademark. That standard may be an APA performance standard, the Voluntary Product Standard PS 1-95 for Construction and Industrial Plywood, or Voluntary Product Standard PS 2-92, "Performance Standards for Wood-Based Structural-Use Panels." Panel quality of all APA trademarked products is subject to verification through an APA audit.

APA's services go far beyond quality testing and inspection. Research and promotion programs play important roles in developing and improving plywood and other panel construction systems, and in helping users and specifiers better understand and apply panel products.

For additional information on wood construction systems, contact APA – The Engineered Wood Association, P.O. Box 11700, Tacoma, Washington 98411-0700.

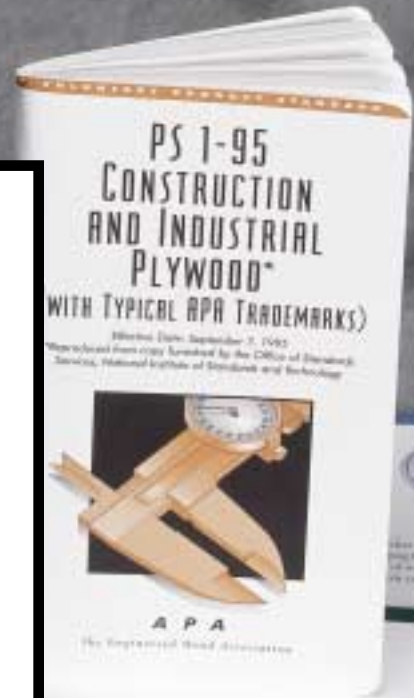
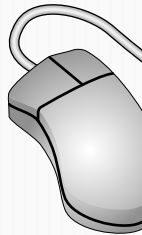
Other publications from APA:

- *Design/Construction Guide: Diaphragms and Shear Walls*, Form L350
- *Design Concepts: Building in High Wind and Seismic Zones*, Form W650
- *Engineered Wood Construction Guide*, Form E30
- *APA Publications Index*, Form B300

### MORE INFORMATION ONLINE

Visit APA's web site at [www.apawood.org](http://www.apawood.org) for more information on engineered wood products, wood design and construction, and technical issues and answers.

Online publication ordering is also available through the web site.





## INTRODUCTION TO LATERAL DESIGN

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Form No. X305C/Revised April 2003/0200

