SEGMENTED AND PERFORATED SHEAR WALLS

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There are two design methodologies used for shear walls: Segmented Design and Perforated Design. This course will illustrate both methods and provide a comparison.

Segmented Shear Wall Design

Segmented Shear Wall Design (SSW) is the traditional design method that has been used for many years. In the SSW method, walls are divided into segments of full-height sheathing. These segments are typically separated by openings in the wall such as doors and windows. The lengths of each full-height sheathing segment (b_i) are summed together, resulting in a conservative estimate of the length of the wall that will resist shear forces. The full-height segments are then designed to resist the applied loads. Hold-down connectors (HD) are required at the bottom corners of each segment to prevent each segment from overturning.

The following illustrations depict a typical shear wall. Figure 1 shows that the wall is made up of six sheathing panels, typically plywood or oriented strand board (OSB) that have been mounted vertically to the framing members. Holes have been framed into the wall to accommodate a window and a door. This wall geometry will be used several times throughout this course.

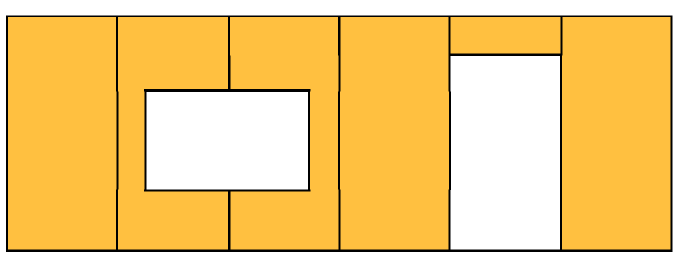


Figure 1 - Wood-frame wall with openings

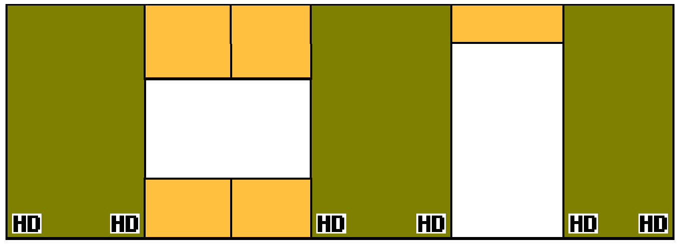


Figure 2 - Segmented shear wall model

Figure 2 illustrates the shear wall divided into full-height sheathing segments, shown in green. Only the full-height sheathing segments are assumed to provide resistance to lateral loads. The sheathing grade and thickness and the nail size and spacing determine the shear capacity per foot of length of the full-height segments. 2009 IBC Table 2306.3 relates these variables so that designers can determine the shear capacity (v) in units of lb/ft (plf) of the full-height segments. The design shear capacity, V, is found using the following equation:

$$V = v \, \Sigma b_i$$

Where:

V = total allowable shear capacity of wall (lb)

v = allowable shear capacity per unit length (lb/ft)

Σb_i = sum of lengths of full-height sheathing segments

ALLOWABLE SHEAR TABLE

It is important for designers to understand how to use 2009 IBC Table 2306.3 "Allowable Shear for Wood Structural Panel Shear Walls."

The table relates sheathing thickness, nail size and spacing, sheathing grade and allowable unit shear to enable determination of an appropriate construction configuration. Depending on the given information, the table may be used in different ways to find the unknown parameters. The tabulated values of allowable unit shear are for shear walls ***sheathed on one side only***. Unit shear values are additive for walls with structural sheathing on both sides.

The following example demonstrates how the table may be used to find the necessary information for design. Keep in mind this is only one approach for using 2009 IBC Table 2306.3.

Problem:

A shear wall will be built using sheathing grade plywood panels (e.g., C-D sheathing) applied over 2x6 Douglas Fir-Larch studs that are 16 inches on center (o.c.). The sheathing will be attached using 8d common nails. The shear wall must resist a unit shear due to seismic loading of 375 plf. Determine the minimum sheathing thickness and the nail spacing to meet these requirements.

Solution:

From the Table, it can be seen that two solutions exist:

A. 8d common nails at 3” spacing at panel edges and 12” in the panel field, using 3/8” minimum sheathing

B. 8d common nails at 4” spacing at panel edges and 12” in the panel field, using 15/32” minimum sheathing

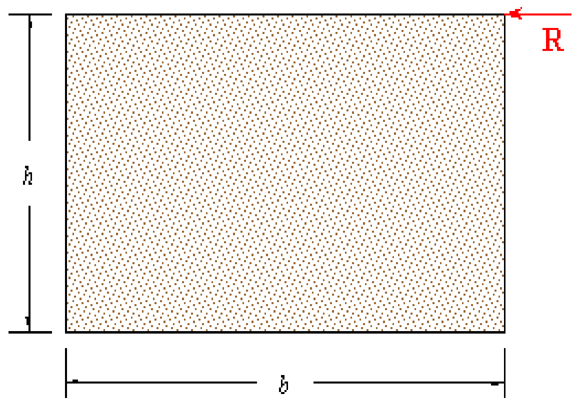
2009 IBC TABLE 2306.3 (MODIFIED)
ALLOWABLE SHEAR (POUNDS PER FOOT) FOR WOOD STRUCTURAL PANEL SHEAR WALLS WITH FRAMING OF DOUGLAS FIR-LARCH OR SOUTHERN PINE FOR WIND OR SEISMIC LOADING

PANEL GRADE	MINIMUM NOMINAL PANEL THICKNESS (inch)	MINIMUM FASTENER PENETRATION IN FRAMING (inches)	PANELS APPLIED DIRECT TO FRAMING				
			NAIL (common or galvanized box) or staple size	Fastener spacing at panel edges (inches)			
				6	4	3	
Sheathing, plywood siding except Group 5 Species	$^{5}/_{16}$ or $^{1}/_{4}$	$1^{1}/_{4}$	6d (2″ × 0.113″ common, 2″ × 0.099″ galvanized box)	180	270	350	
		1	1½ 16 Gage	145	220	295	
	$^{3}/_{8}$	$1^{1}/_{4}$	6d (2″ × 0.113″ common, 2″ × 0.099″ galvanized box)	200	300	390	
		$1^{3}/_{8}$	8d (2½″ × 0.131″ common, 2½″ × 0.113″ galvanized box)	220	320	410	
		1	1½ 16 Gage	140	210	280	
	$^{7}/_{16}$	$1^{3}/_{8}$	8d (2½″ × 0.131″ common, 2½″ × 0.113″ galvanized box)	240	350	450	
		1	1½ 16 Gage	155	230	310	
	$^{15}/_{32}$	$1^{3}/_{8}$	8d (2½″ × 0.131″ common, 2½″ × 0.113″ galvanized box)	260	380	490	
		1½	10d (3″ × 0.148″ common, 3″ × 0.128″ galvanized box)	310	460	600	
		1	1½ 16 Gage	170	255	335	
	$^{19}/_{32}$	1½	10d (3″ × 0.148″ common, 3″ × 0.128″ galvanized box)	340	510	665	
		1	$1^{3}/_{4}$ 16 Gage	185	280	375	
			Nail Size (galvanized casing)				
	$^{5}/_{16}$	$1^{1}/_{4}$	6d (2″ × 0.099″)	140	210	275	
	$^{3}/_{8}$	$1^{3}/_{8}$	8d (2½″ × 0.113″)	160	240	310	

WALL SHEAR

You should now understand how to use the IBC Allowable Shear Tables for shear walls. Most of the parameters (nail size, sheathing thickness, etc.) from the allowable shear tables are relatively straightforward to understand. The allowable unit shear deserves some attention however. Unit shear (v) is the resultant lateral load (R) from the horizontal diaphragm, divided by the sum of the lengths of the full-height sheathing segments.

Single Panel Shear Wall



$v = R / b$

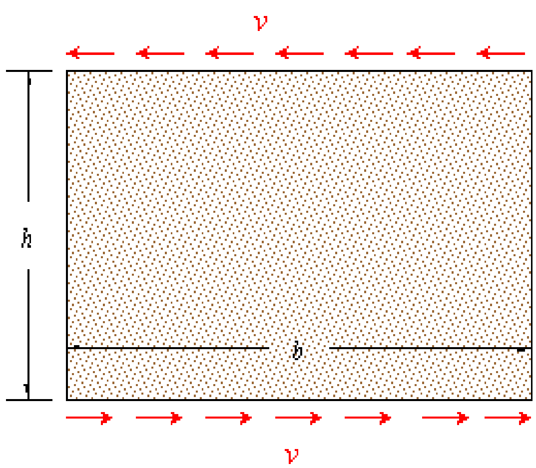
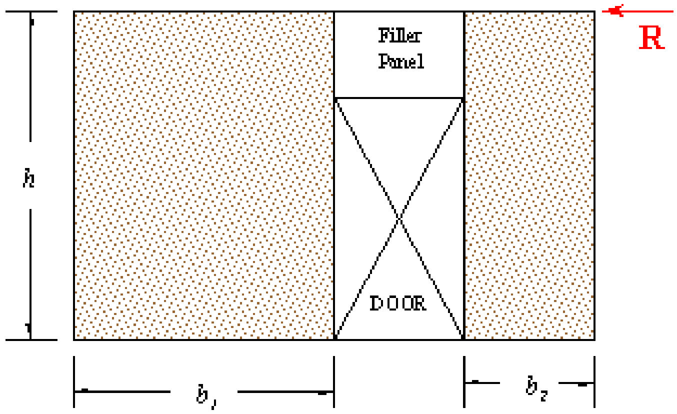


Figure 3 – Single Panel Shear Wall

Multi-panel Shear Wall (segmented)



$v = R / (b_1 + b_2)$

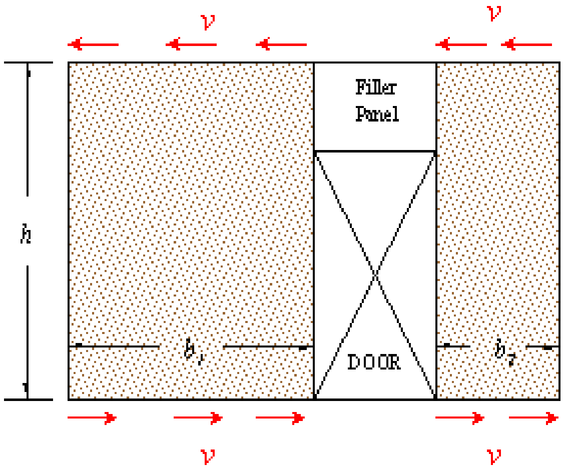


Figure 4 – Multi-panel Shear Wall

From Figure 4, it can be seen that if a door is placed in the shear wall, the unit shear (v) increases. The same is true for windows or other openings in the shear wall. It can also be shown that a longer shear wall will have a lower unit shear than a shorter one, thus permitting the use of thinner sheathing and fewer (or smaller) nails.

Dimension Ratios

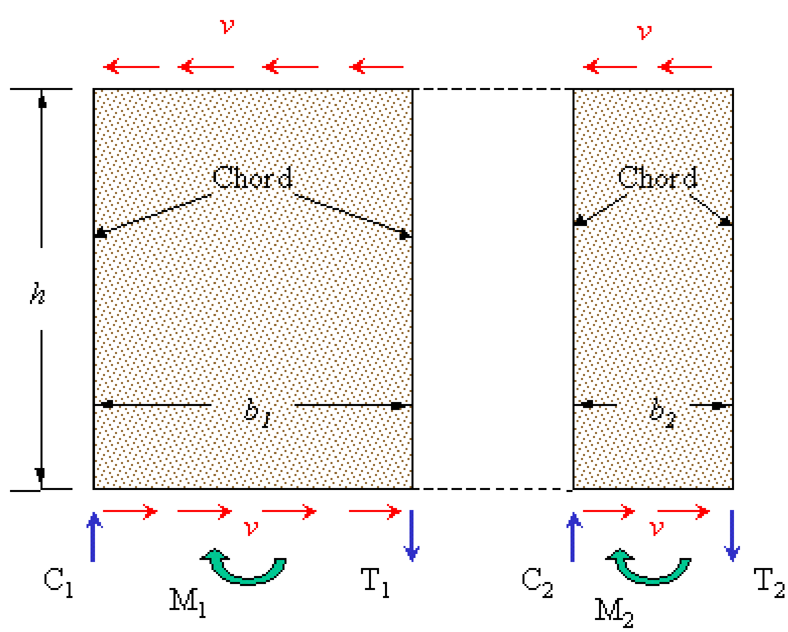
The International Building Code (IBC) places limits on the dimensions of wood-frame shear walls. These restrictions are based on the poor performance of tall, narrow wood-frame shear wall segments. The limits are in the form of maximum height-to-width ratios (h:b).

Material	**Shear Walls** Maximum Height :Width
Wood Structural panels nailed all edges	3-1/2 : 1

CHORD DESIGN

The vertical members at either end of a shear wall are called chords. In the Segmented Shear Wall (SSW) design method, chords are provided at each end of every shear wall segment (i.e., on either side of every door or window opening, and at corners/ends of walls) and are designed to resist the moment acting in the shear wall segment. In the Perforated Shear Wall (PSW) shear wall design method, chords are only provided at each end of the entire shear wall and are designed to resist the entire moment acting in the shear wall. The moment subjects the chords to axial loads, either compression or tension.

A typical method of analysis for chords in wood-frame walls is to use the overturning moment in the shear wall (or shear wall segment) to determine chord forces.



Gross Overturning Moment:

$M_1 = v * b_1 * h$

$M_2 = v * b_2 * h$

Chord Forces:

$T_1 = C_1 = M_1 / b_1 = vh$

$T_2 = C_2 = M_2 / b_2 = vh$

Chords must be designed for both tensile and compressive forces. The compression chord may also carry gravity loads in addition to the forces associated with the overturning moment. The tension chord may need to resist wind uplift forces in addition to the forces caused by lateral loads. In order to resist the large tensile and compressive forces, chords are typically composed of doubled full height studs.

Because the chords may be subjected to very high axial compression forces it is important to consider the sill plates that the chords bear on. Crushing of the sill plates (bottom plates) is a common mode of failure for shear walls subjected to large overturning moments. Therefore, when designing the sill plates, compression perpendicular to grain strength of sill plates should be considered.

ANCHORAGE

Anchorage refers to the connectors that attach the structure to the foundation to resist the applied lateral loads. Anchorage forces refer to the transfer of vertical (gravity and uplift) loads, lateral forces perpendicular to the wall, and lateral forces parallel to the wall.

There are two basic type of anchors. The first type are called hold-downs (tie-downs) and are the connectors used at the ends of shear wall segments to resist overturning moments. Hold-downs must transmit the tensile force from a shear wall chord to the foundation of the structure. The second type are called anchor bolts (sill plate bolts). These bolts are evenly spaced along the bottom length of the shear wall and primarily resist sliding action from lateral loads.

Anchorage is a connection design problem. The forces are straightforward to calculate as they are simply the uplift forces required at the chords of the shear wall to prevent overturning, and the unit shear along the base of the shear wall to prevent sliding.

DEFLECTION

There are two primary reasons for limiting shear wall deflection (also known as *story drift*). The first reason is for serviceability in order to limit cracking in wall coverings such as plaster, gypsum, and paint. The second reason has to do with limiting the maximum inelastic response of the shear wall, which is important in the seismic design of wood buildings. Furthermore, the story drift is also used to determine the relative flexibility or rigidity of diaphragms and shear walls.

The method for calculating shear wall deflection can be found in 2009 IBC 2305.3. It accounts for bending, shear, nail deformation and anchorage slip.

- Bending: the shear wall performs like a cantilevered beam with the chords acting as the flanges of an I-beam.

- Shear: the wall sheathing carries the shear like the web of a deep I-beam.

- Nail Slip: slip in the nail connections between the sheathing and the framing allows relative movement of the sheathing panels.

- Anchorage: Slip may occur between the chords and the hold-down connector, or between the hold-down connector and the foundation.

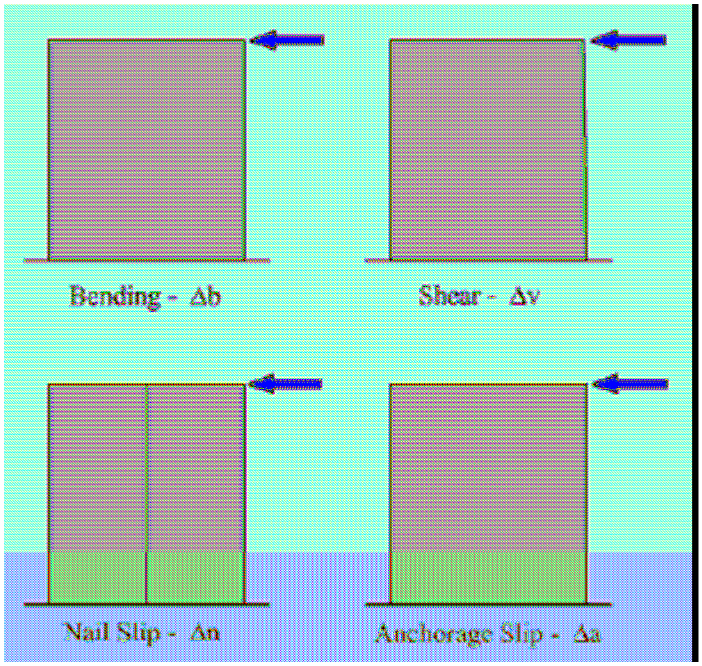


Figure 5 – Shear Wall Deflection

Total shear wall deflection (story drift) is the sum of the deflections from each of these components.

$$\Delta_s = \Delta_b + \Delta_v + \Delta_n + \Delta_a$$

$$\Delta_b := \frac{8 \cdot v \cdot h^3}{E \cdot A \cdot b}$$

$$\Delta_v := \frac{v \cdot h}{G \cdot t}$$

$$\Delta_n := \frac{3}{4} \cdot h \cdot e_n$$

$$\Delta_a := \frac{h}{b} \cdot d_a$$

b = length of shear wall

A = cross-sectional area of chord

E = modulus of elasticity of chord

h = shear wall height

v = unit shear

t = effective thickness of structural sheathing panel

G = modulus of rigidity of structural sheathing panel

e_n = nail deformation under load

d_a = hold-down deflection

PERFORATED DESIGN:

The perforated shear wall (PSW) design methodology is similar to the segmented shear wall (SSW) method but only requires two hold-downs for each wall (one at each end), thus eliminating the intermediate overturning restraints located adjacent to window and door openings in the SSW method. The PSW method recognizes that the entire wall acts to resist overturning, rather than a series of individual full-height segments. The result is a wall with slightly lower capacity (a function of the sizes of openings) and reduced cost in material and labor due to elimination of intermediate hold-downs. Intuitively, a PSW with a small opening would have nearly the same capacity as the same wall without openings. As the size of the opening(s) increases, the capacity is correspondingly reduced. In many cases wood-framed walls have excess capacity when designed according to the SSW methodology, while the PSW method results in a more economical design.

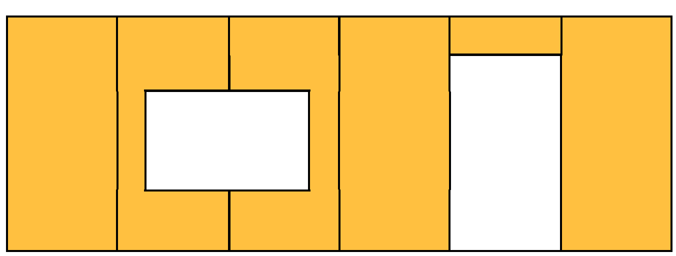


Figure 6 - Wood-frame shear wall with openings

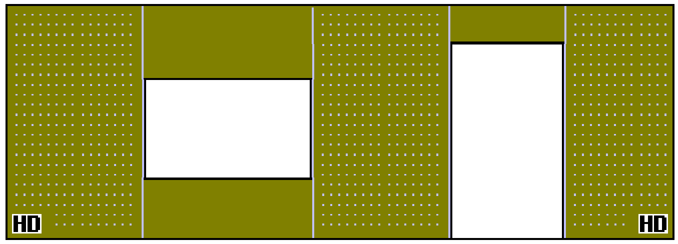


Figure 7 - Perforated shear wall model

Determining the capacity of a PSW, or shear wall with unrestrained openings, is similar to the SSW method. However, in the PSW method all sheathed portions of the shear wall (shaded in green) are assumed to provide resistance to lateral loads. PSW capacity is based on the capacity of the wall from the SSW method, reduced by an opening adjustment factor that is related to the percentage of full-height sheathing in the wall.

The first step in PSW design is to determine the unit shear capacity (*v*) of the SSW using IBC Table 2306.3, as was demonstrated previously for segmented shear walls. Next, the shear capacity adjustment factor (C_o) must be calculated using the tabulated information below. Note that the value of C_o is always less than or equal to unity since a PSW has fewer hold-downs than a SSW.

Percent full-height sheathing = $\sum b_i / L$

where:

L = total length of the wall

b_i= length of full-height sheathing segment

h = height of shear wall

	Maximum Unrestrained Opening Height (Door or Window)				
	h/3	h/2	2h/3	5h/6	h
8 ft wall	2'-8"	4'-0"	5'-4"	6'-8"	8'-0"
10 ft wall	3'-4"	5'-0"	6'-8"	8'-4"	10'-0"
Percent full-height sheathing	Shear Capacity Adjustment Factor (C_o)				
0%	1.00	0.67	0.50	0.40	0.33
10%	1.00	0.69	0.53	0.43	0.36
20%	1.00	0.71	0.56	0.45	0.38
30%	1.00	0.74	0.59	0.49	0.42
40%	1.00	0.77	0.63	0.53	0.45
50%	1.00	0.80	0.67	0.57	0.50
60%	1.00	0.83	0.71	0.63	0.56
70%	1.00	0.87	0.77	0.69	0.63
80%	1.00	0.91	0.83	0.77	0.71
90%	1.00	0.95	0.91	0.87	0.83
100%	1.00	1.00	1.00	1.00	1.00

The unrestrained opening height is the vertical dimension of any opening in the wall. The maximum unrestrained opening height is the vertical dimension of the tallest opening in the wall, expressed as a fraction of the total shear wall height (h). Openings may be located vertically between two sheathing elements (windows), between a sheathed element and the floor (doors), or between the top of the wall and the floor (large doors, or windows and doors without structural sheathing above/below openings). Any areas of the wall that are not sheathed with structural panels such as plywood or OSB are considered unrestrained openings. The PSW method makes the conservative assumption that all unrestrained openings in the wall have the same height as the maximum vertical opening dimension in the wall.

Once the shear capacity adjustment factor (C_o) is determined, it is used to calculate the allowable shear capacity of the perforated shear wall (V_{PSW}) as follows:

$$V_{PSW} = C_o \, v \, \Sigma b_i$$

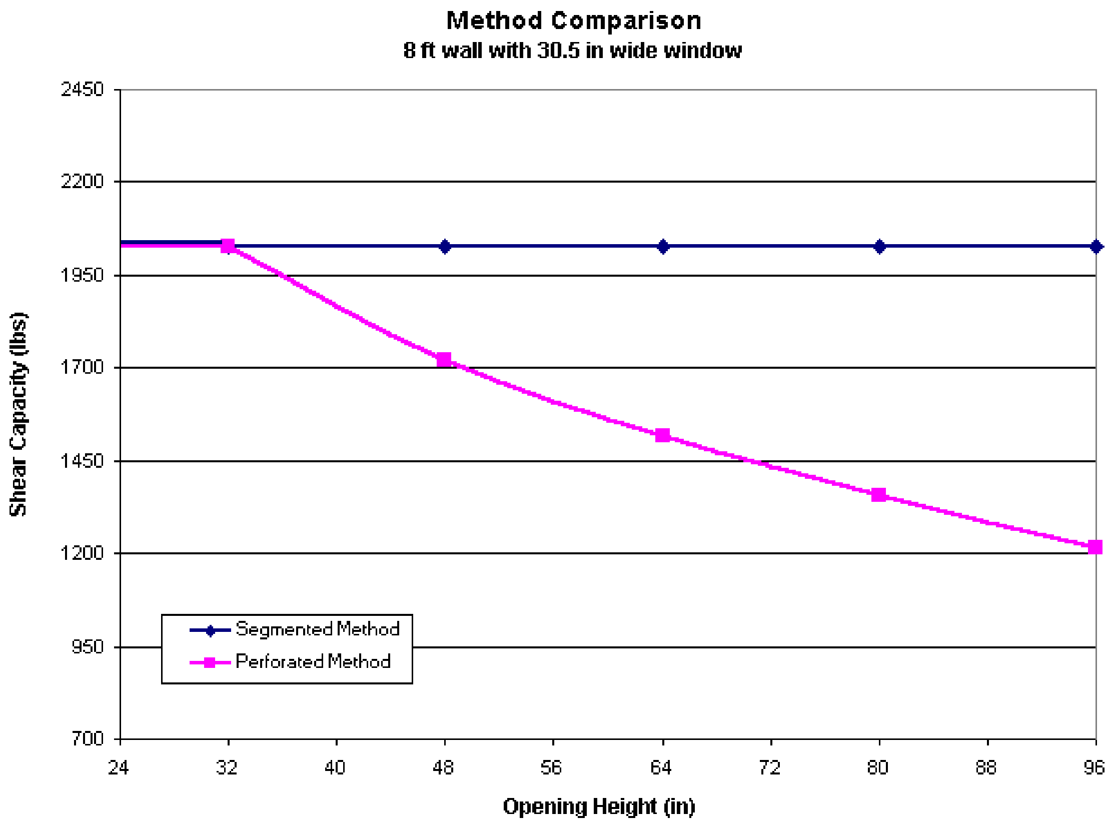
COMPARISON OF DESIGN METHODS

Two shear wall design methodologies have been presented in this tutorial. Both methods have advantages and disadvantages.

The segmented shear wall (SSW) approach is the "tried and true" method. It relies only on the segments of full-height sheathing to resist shear, and neglects the effects of sheathing above and below openings. In general it yields a higher design shear capacity than the perforated shear wall (PSW) method. However, the SSW method also requires hold-downs at the bottom corners of each full-height shear wall segment to resist overturning. This may result in a large number of hold-downs which are labor-intensive to install and add cost to a project.

The perforated shear wall (PSW) design approach is the newer method, having been developed in the early 1980's by Professor Hieto Sugiyama in Japan. The PSW method takes into consideration the contribution to shear resistance of the sheathing located above and below openings, and reduces the required number of hold-downs. However, the PSW method typically results in lower shear capacity for a given wall. This is oftentimes acceptable since shear walls designed using the traditional SSW method frequently have excess shear capacity. The following chart illustrates a comparison between allowable shear capacities for the SSW method versus the PSW method.

This chart presents the calculated shear capacities for 8 ft by 8 ft walls with a 30.5 in. wide window that varies in height from 24 in. to a full wall height of 96 in. It is important to note that regardless of the opening height, the SSW method gives the same capacity (2025 lb), whereas the PSW method provides decreased capacity as the amount of sheathing above/below the window decreases.



Method Comparison
8 ft wall with 30.5 in wide window
2450
2200
1950
1700
1450
1200
950
700
Shear Capacity (lbs)
24
32
40
48
56
64
72
80
88
96
Opening Height (in)
Segmented Method
Perforated Method