



Perforated Shearwall Design

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Introduction

In the segmented approach to wood frame shearwall design, shearwall segments extend the full-height of the wall with hold-downs on each end of the shearwall segment. Walls with openings consist of multiple shearwall segments, also with hold-downs on each end of each segment. Recent code developments have allowed for a new approach, called the *perforated shearwall method*, which considers the walls, with openings, as one unified shearwall with one hold-down at each end.

Figure 1 shows a shearwall composed of three shearwall segments. Each segment has hold-downs at each end to provide overturning restraint. The design capacity of the shearwall is calculated as the sum of the capacities of each shearwall segment. The contribution of sheathing above and below openings is typically ignored; thus, the method does not take into account the inherent structural capacities of the sheathed wall system.

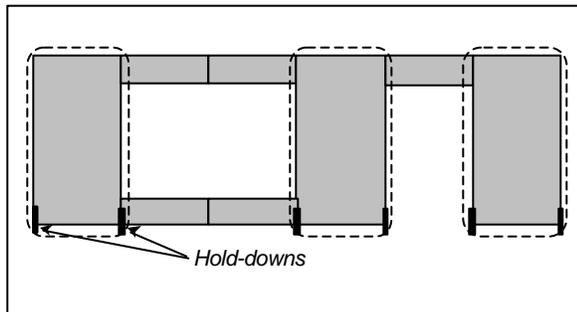


Figure 1 : The segmented shearwall.

Figure 2 illustrates the perforated shearwall. The wall is identical in construction to the segmented shearwall shown in Figure 1, but the interior hold-downs are not required. The capacity of the perforated shearwall is less than the segmented shearwall containing multiple shearwall segments, each fully restrained against overturning. This is true because of the reduced end restraint provided to the shearwall segment. Despite a reduction in capacity, the perforated shearwall may have sufficient capacity for the particular application, while eliminating the need for interior hold-downs.

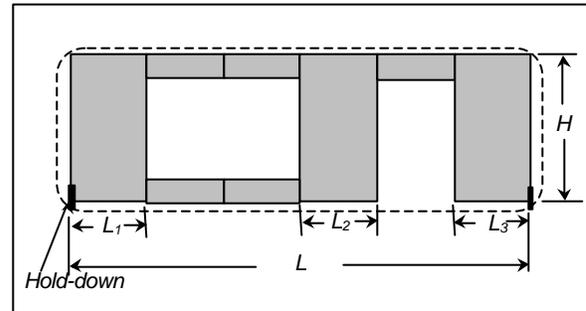


Figure 2 : The perforated shearwall. Only two hold-downs are required.

This approach is based on an empirical equation for shear capacity and stiffness proposed by Professor Hideo Sugiyama, at the University of Tokyo, in 1981. Later, substantial testing in the U.S. and Canada verified the equation's accuracy.

Design examples using the perforated shearwall method and the segmented shearwall approach typically address only one-story construction. A two-story perforated shearwall example is described in this article. The example, developed for the Recommended Provisions for Seismic Regulations for New Buildings and Other Structures (2000 NEHRP), is modified to address wind loading using an allowable strength design approach.

Design Provisions

In 1995, the Southern Building Code Congress International (SBCCI) became the first model building code to recognize the perforated shearwall design methodology when it approved an amendment to the 1994 *Standard Building Code* (SBC, 1994 revised). Today, the perforated shearwall method is included in the 2000 *International Building Code*, AF&PA's *Wood Frame Construction Manual for One- and Two- Family Dwellings*, and the 2000 NEHRP *Recommended Provisions for Seismic Regulations for New Buildings* (2000 NEHRP).

The basic method for determining the design shear capacity of a perforated shearwall is the same in each of the code documents above. However, requirements for shear and uplift forces between wall ends vary. For example, the 2000 NEHRP provisions provide an equation format for determining shear and

uplift forces between wall ends. This equation format provides a convenient means for calculating anchorage requirements based on the shear force resisted by the perforated shearwall, and is described in detail in this article. Tension and compression forces required for end posts are also provided in equation format.

Design Equations

Basic equations for design shear capacity, and calculation of anchorage and chord forces follow:

Design shear capacity:

The design shear capacity, V_{wall} , of a perforated shearwall is calculated as:

$$V_{wall} = (v C_o) \Sigma L_i \quad (1)$$

where:

- V_{wall} = design shear capacity of a perforated shearwall (lbs)
- v = unadjusted unit shear capacity (plf) equal to the tabulated design unit shear capacity of a segmented shearwall.
- C_o = shear capacity adjustment factor from Table 1 which accounts for the strength reducing effect of openings on shearwall capacity.
- ΣL_i = sum of lengths of perforated shearwall segments (feet). A perforated shearwall segment is a section of shearwall with full height sheathing and which meets minimum aspect ratio requirements in the governing building code.

Uplift anchorage at perforated shearwall ends:

Anchorage for uplift forces, R , due to overturning is calculated as:

$$R = \frac{Vh}{C_o \Sigma L_i} \quad (2)$$

where:

- R = anchorage uplift reaction force (lbs)
- V = shear force in perforated shearwall (lbs)
- h = shearwall height (feet)

Anchorage force for in-plane shear:

The unit shear force, v , transmitted into the top of a perforated shearwall, out of the base of the perforated shearwall at full height sheathing, and into collectors (drag struts) connecting shearwall segments, is calculated as:

$$v = \frac{V}{C_o \Sigma L_i} \quad (3)$$

where:

- v = unit shear force (plf)

Uplift anchorage between perforated shearwall ends:

Perforated shearwall bottom plates at full height sheathing must be anchored for a uniform uplift force, t , equal to the unit shear force, v , calculated in Equation 3.

Tension and Compression chords:

Each end of each perforated shearwall segment must be designed for a tension force, T , or a compression force, C , equal to the uplift anchorage reaction force, R , calculated in Equation 2.

Other General Requirements

A perforated shearwall segment of minimum length must be located at each end of a perforated shearwall. The minimum length is tied to the minimum aspect ratio, h/L , requirement in the governing building code. In most cases, this ratio is 3½:1 for shearwalls resisting wind and low seismic forces. Aspect ratio limits also apply to interior segments used in calculation of design shear capacity. Other general requirements for perforated shearwalls follow those for the segmented shearwall. Top and bottom of wall elevations are to be continuously in-plane. Walls containing out-of-plane offset segments are to be considered as separate shearwall segments, as seen as heavy lines in Figure 3.

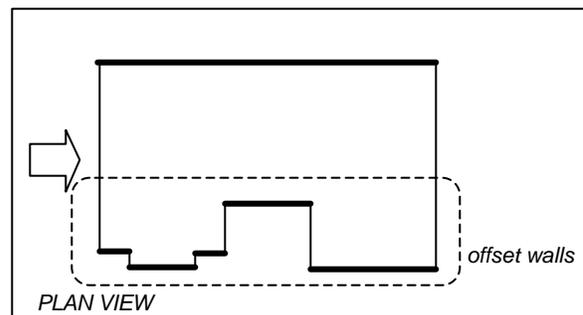


Figure 3: In-plane vs. offset walls

Anchorage for uplift forces due to overturning is required at each end of the perforated shearwall. The uplift force at each wall end is determined by Equation 2. A continuous load path to the foundation should be maintained for all overturning forces (e.g. from story above).

It is required that fastening be provided along the length of the bottom plate of wall sections sheathed

full-height to resist distributed shear and uplift forces between wall ends as calculated in Equation 3. A continuous load path to the foundation should be maintained for all uplift forces (e.g. from story above). When maintaining a load path for shear, lower floor shearwalls need only consider shear force, V , in the shearwall above, and not the shear force divided by C_o when adequate collectors are provided. The fastening requirements calculated in Equation 3 conservatively account for the non-uniform distribution of shear within a perforated shearwall. Prescribed forces for shear and uplift connections ensure that the capacity of the wall is governed by the sheathing to framing attachment (e.g. shearwall nailing) and not bottom plate attachment for shear and/or uplift.

Example

A design example involving a simple two-story building (see Figure 4) demonstrates application of the method proposed in the 2000 NEHRP provisions. Design shear capacity, shear and uplift between wall ends, and end post forces are calculated. Only lateral loads due to wind are considered. Building dead load and wind uplift forces are not considered. Once forces are determined, two detailing options are considered. Configuration A uses a continuous rim joist at the second floor level sized to resist localized uplift forces along the base of the wall due to story shear forces. Configuration B considers a condition where there is blocking between joists (e.g. floor framing runs perpendicular to the perforated shearwall).

Second Floor Wall:

Design shear capacity:

Percent full-height sheathing = $(4\text{ ft} + 4\text{ ft}) / 16\text{ ft} \times 100 = 50\%$

Maximum opening height ratio = $4\text{ ft} / 8\text{ ft} = 0.50$

Shear capacity adjustment factor, C_o , from Table 1 = 0.80

$$V_{wall} = (v C_o) \Sigma L_i \\ = (365\text{ plf})(0.80)(8\text{ ft}) = 2336\text{ lbs}$$

$$2336\text{ lbs} > 2000\text{ lbs} \quad \text{OK}$$

Note that $v = 365\text{ plf}$ is for 15/32 rated sheathing with 8d common nails (0.131 by 2 1/2 in.) at 6 inch perimeter spacing resisting wind load.

Uplift at shearwall ends due to overturning:

$$R = \frac{Vh}{C_o \Sigma L_i} = \frac{(2000\text{ lbs})(8\text{ ft})}{(0.80)(8\text{ ft})} = 2500\text{ lbs}$$

Anchorage force for in-plane shear:

$$v = \frac{V}{C_o \Sigma L_i} = \frac{(2000\text{ lbs})}{(0.80)(8\text{ ft})} = 313\text{ plf}$$

Anchorage force for uplift, t , between wall ends:

$$t = v = 313\text{ plf}$$

Tension chord force, T , and compression chord force, C , at each end of a perforated shearwall segment:

$$C = T = R = 2500\text{ lbs}$$

First floor wall

Design shear capacity:

Percent full-height sheathing = $(4\text{ ft} + 4\text{ ft}) / 12\text{ ft} \times 100 = 67\%$

Maximum opening height ratio = $4\text{ ft} / 8\text{ ft} = 0.50$

Shear capacity adjustment factor, C_o , from Table 1 = 0.86

$$V_{wall} = (v C_o) \Sigma L_i \\ = (530\text{ plf})(0.86)(8\text{ ft}) = 3646\text{ lbs}$$

$$3646\text{ lbs} > 3500\text{ lbs} \quad \text{OK}$$

Note that $v = 530\text{ plf}$ is for 15/32 rated sheathing with 8d common nails (0.131 by 2 1/2 in.) at 4 inch perimeter spacing resisting wind load.

Uplift at shearwall ends due to overturning:

$$R = \frac{Vh}{C_o \Sigma L_i} = \frac{(3500\text{ lbs})(8\text{ ft})}{(0.86)(8\text{ ft})} = 4070\text{ lbs}$$

When maintaining load path from story above:

$$R = R_{\text{from second floor}} + R_{\text{from first floor}} \\ = 4070\text{ lbs} + 2500\text{ lbs} = 6570\text{ lbs}$$

Anchorage force for in-plane shear:

$$v = \frac{V}{C_o \Sigma L_i} = \frac{(3500\text{ lbs})}{(0.86)(8\text{ ft})} = 509\text{ plf}$$

Anchorage force for uplift, t, between wall ends:

$$t = v = 509 \text{ plf}$$

Uplift, t , can be cumulative with 313 lbs from the story above to maintain load path. Whether this occurs depends on detailing for transfer of uplift forces between wall ends.

Tension chord force, T, and compression chord force, C, at each end of a perforated shearwall segment:

$$C = T = R = 4070 \text{ lbs}$$

When maintaining load path from story above,

$$C = 4070 \text{ lbs} + 2500 \text{ lbs} = 6570 \text{ lbs.}$$

Load Path

Configuration A detailing (see Figure 5) uses a continuous rim joist at the second floor. The rim joist is sized to resist induced bending stresses resulting from second story uplift forces between wall ends. Nails in the second story wall bottom plate to rim joist connection resist uplift between wall ends, and holddowns at the ends of the second story wall provide continuity of load path for these forces. Transfer of shear from the second story to the first story is through nails in the wall bottom plate to rim joist connection and toe nails in the rim joist to wall top plate connection. First floor anchor bolts with sized plate washers provide for transfer of shear and uplift forces between wall ends to the foundation. First floor holddowns are sized to resist uplift forces due to story shear and may also include uplift forces from the story above when maintaining a load path to the foundation.

Configuration B detailing (see Figure 6) addresses the situation where a continuous rim joist is not provided, such as when floor framing runs perpendicular to the shearwall with blocking between floor framing members. Nails are used in the second story wall bottom plate-to-blocking connection and toe nails are used in the rim joist-to-wall top plate connection to transfer in-plane shear forces. Transfer of shear to the foundation is provided by anchor bolts in the first story wall bottom plate-to-concrete connection. Transfer of uplift forces between wall ends, from the second story to the first story, is accomplished by use of metal strapping. This load path is maintained by strapping into the foundation or lapping the strap around the first story bottom plate. When the strap is lapped around the bottom plate, the anchor bolt and plate washer must be sized to resist

the induced forces. First floor holddowns are sized to resist uplift forces due to first story shear and may also include uplift forces from the story above when maintaining a load path to the foundation.

In Configuration A and B, distributed fastening for shear and uplift between wall ends is provided over the length of full-height sheathed wall sections. With no other specific requirements, the fastening between the full height segments will be controlled by minimum construction fastening requirements. For bottom plates on wood platforms this would require one 16-penny common nail at 16 inches on center. In some cases, it may be preferable to extend a single bottom plate fastening schedule across the entire length of the perforated shearwall rather than require multiple fastening schedules.

Summary

This example demonstrates one application for use of perforated shearwalls. An equation format for determining shear and uplift forces between wall ends provides a convenient means of calculating anchorage requirements based on the shear force resisted by the perforated shearwall. The design strength is less than would be achieved if the segmented approach for shearwall design were used (e.g. each segment has holddowns at each end). However, sufficient strength to resist the applied loads can often be provided with holddowns at wall ends only. Use of perforated shearwalls does not provide a remedy for those situations where the amount of wall sheathing is limited, making the segmented approach insufficient for the applied loads. Walls with larger amounts of sheathing present the best opportunity for application of the perforated shearwall method.

References

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SBC (1994R). *Standard Building Code (SBC) Wood Section 1994 edition with 1996 revisions*, Standard Building Code Congress International, Birmingham, AL.

Sugiyama, Hideo. 1981. *The Evaluation of Shear Strength of Plywood-Sheathed Walls with Openings*. Mokuzai Kogyo (Wood Industry). 36-7, 1981.

WFCM (1996). *Wood Frame Construction Manual for One- and Two- Family Dwellings - 1995 SBC High Wind Edition*, American Forest & Paper Association. 235 p, Washington, DC.

Table 1: Shear Capacity Adjustment Factor

WALL HEIGHT (h)	MAXIMUM OPENING HEIGHT RATIO ^a AND HEIGHT				
	h/3	h/2	2h/3	5h/6	h
8'-0"	2'-8"	4'-0"	5'-4"	6'-8"	8'-0"
10'-0"	3'-4"	5'-0"	6'-8"	8'-4"	10'-0"
Percent Full-Height Sheathing ^b	Shear Capacity Adjustment Factor				
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

- a. The maximum opening height ratio is calculated by dividing the maximum opening clear height by the shearwall height, h. If areas above and below an opening remain unsheathed, the height of the opening shall be defined as the height of the wall.
- b. The percent of full height sheathing is calculated as the sum of widths of perforated shearwall segments divided by the total width of the perforated shearwall including openings.

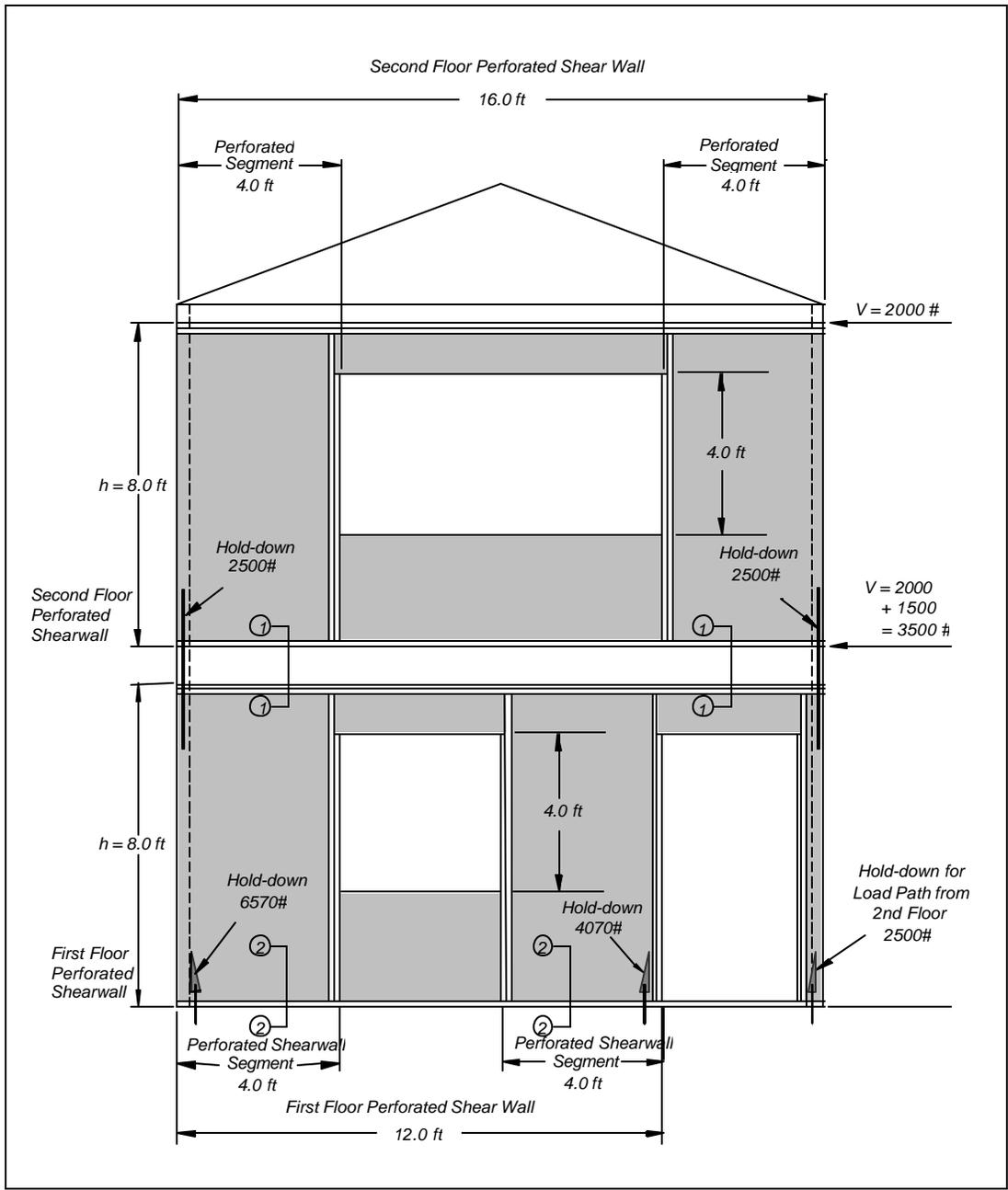


Figure 4: 2 Story Building with Perforated Shearwalls

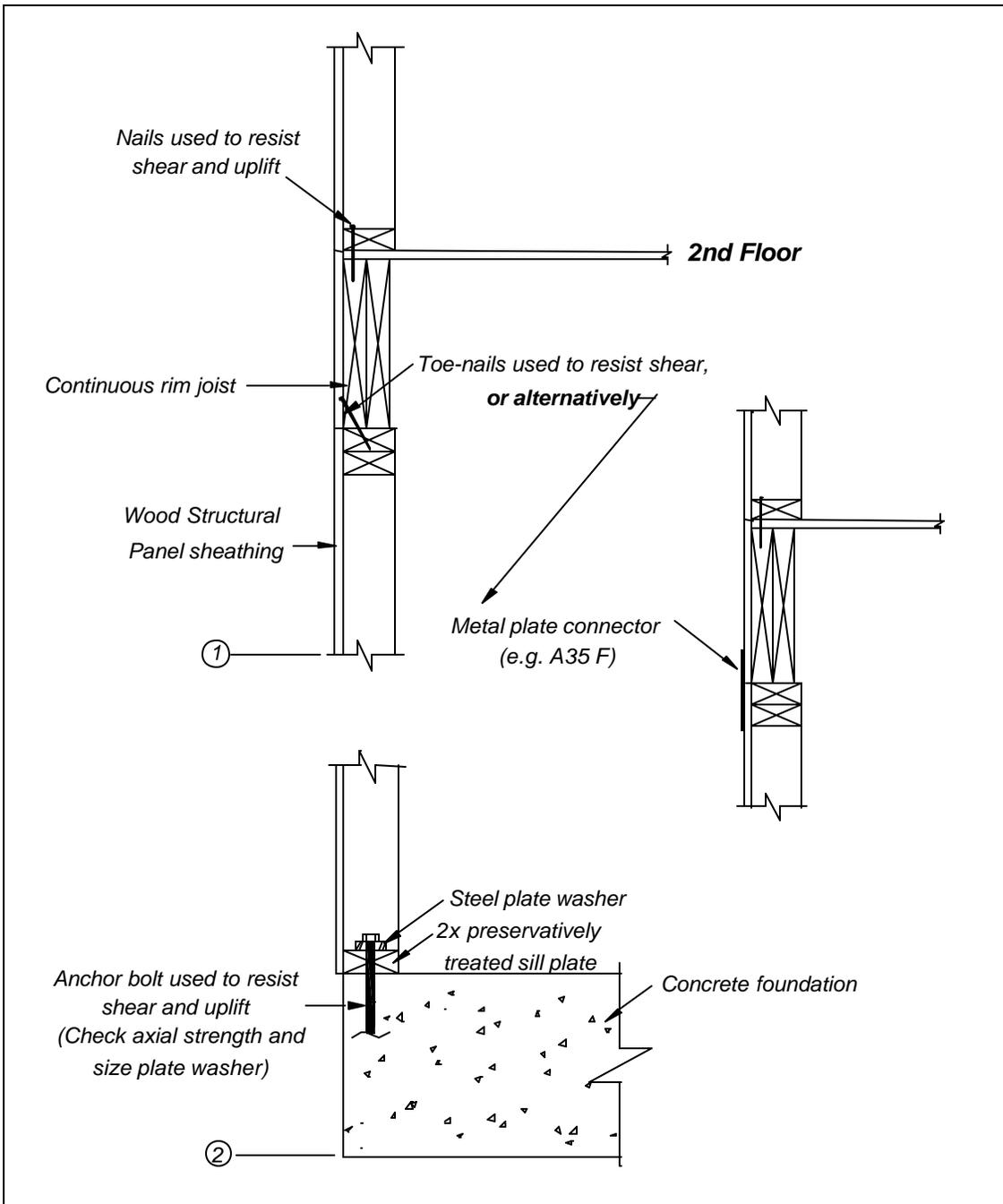


Figure 5: Configuration A Detail – Continuous Rim Joist.

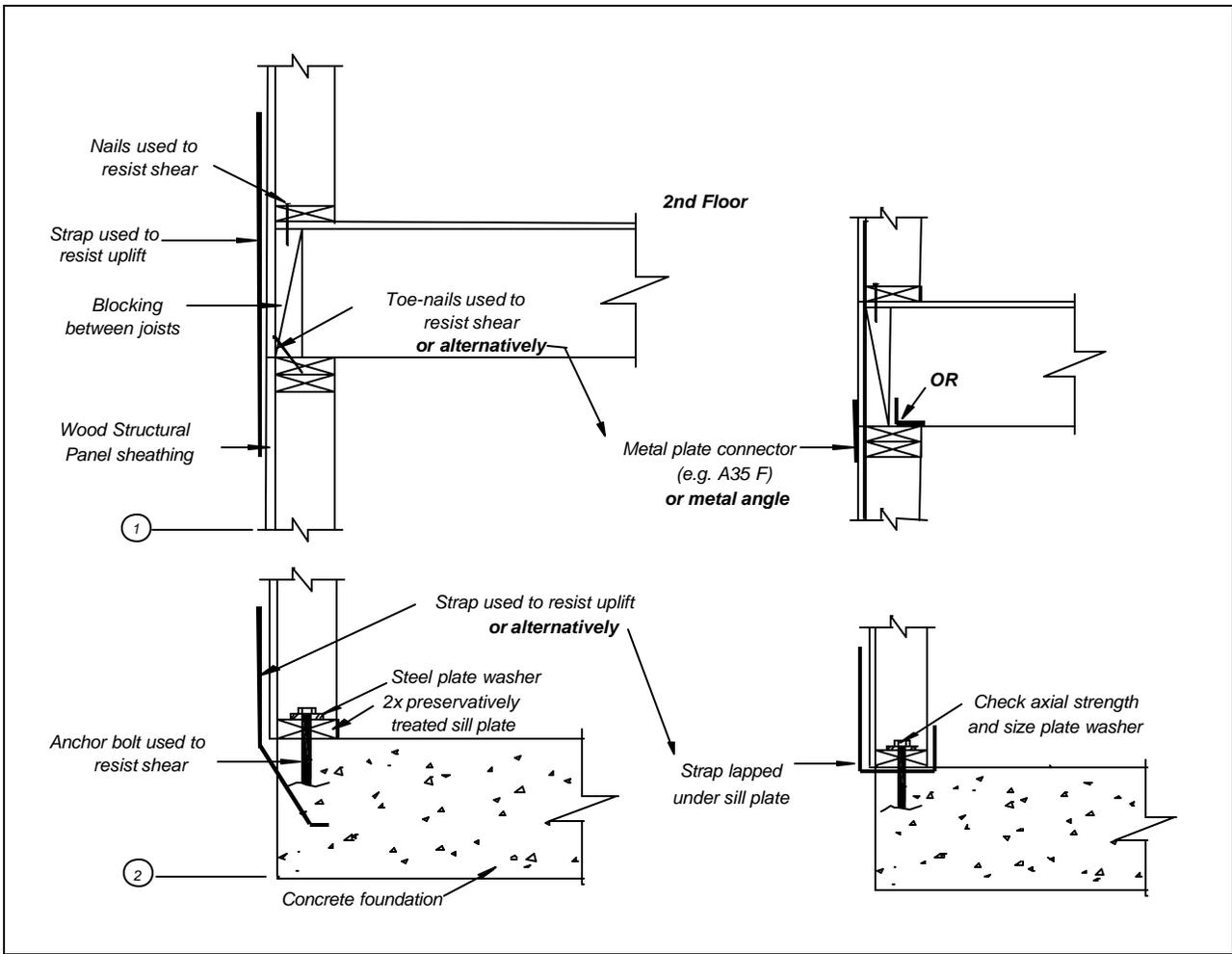


Figure 6: Configuration B Detail – Blocking Between Joists.