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Anchorage of Wood Shear Walls to Concrete for Tension and Shear

2009 IBC brings about several changes from 2006 IBC

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Since the publication of the 2006 International Building Code (IBC), new research and testing related to wood shear walls and concrete anchorage have led to significant changes in the 2009 IBC, code-referenced material standards, product evaluation criteria and industry practice. The first change engineers will likely encounter is the removal of much of the wood shear wall design information from Section 2305 of the IBC. The code now requires the use of AF&PA's 2008 Special Design Provisions for Wind and Seismic (SDPWS-08) to design the lateral-force-resisting system. Since the format of the SDPWS-08 is different from the IBC, some of the other changes are not quite as apparent yet they will impact the way wood shear walls are designed and constructed.

The SDPWS-08, however, does not contain everything needed to complete the design. After engineers determine the connections required at the base of the shear wall, they must then use the IBC and ACI 318-08 to design the anchorage into the concrete. If proprietary connectors or anchors are implemented, designers will need to ensure the products are approved for the application by the authority having jurisdiction. Most building departments and designers rely on research reports issued by an accredited product certification body, such as ICC-ES or IAPMO-ES, to evaluate code compliance.

Designing the anchorage of shear walls is a multi-step process. Understanding the purpose of each step is important to ensure the finished product performs as expected. The process begins with determining the magnitude and location of the shear wall anchorage using the SDPWS-08.

Wood Shear Wall Mechanics and Anchor Forces

Figure 1 shows an idealized force diagram for the shear wall framing when a shear load is applied at the top. The shear force is transferred into the sheathing by nailing the panel into the top plate and transferred out of the sheathing by nailing the panel to the sole plate. Nails into the vertical edges of the sheathing panel prevent the panel from rotating, which results in tension and compression at the shear wall end posts. The shear wall must be anchored to resist uplift due to overturning and shear due to sliding.

The overturning forces for a shear wall are given in SDPWS-08 Equation 4.3-7 for *Individual Full Height Shear Wall Segments*, and Equation 4.3-8 for *Perforated Shear Wall Segments*:

Eqn. 4.3-7: $T = C = vh$

Eqn. 4.3-8: $T = C = (Vh) / (C_o \sum L_i)$

<u>Where:</u>

T = tension force (lbs.)
C = compression force (lbs.)
h = shear wall height (ft.)
v = induced unit shear (lbs./ft.)
V = induced shear force (lbs.)
C_o = shear capacity adjustment factor
$\sum L_i$ = sum of perforated shear wall segment lengths (ft.)

Designers should be cautioned that these equations do not include several factors that impact the design of the framing members and connections. For multi-story applications, overturning forces from shear walls above are cumulative and require careful detailing for load path. In addition, dead load above the shear wall end posts can reduce the tension force and increase the compression force. Finally, for narrow shear walls (aspect ratio, h:b, greater than 1:1 as a general rule), using a moment arm measured from center of tension (hold-down anchor) to center of compression (end post) can significantly increase the overturning forces compared to Eqn. 4.3-7, which uses a moment arm equal to the full length of shear wall (b).

The shear anchorage of the sole plate for an *Individual Full Height Shear Wall Segment* must be designed to transfer the induced unit shear force (v). For *Perforated Shear Wall Segments,* the sole plate anchorage must be designed to resist the maximum-induced unit shear from Equation 4.3-9.

Eqn. 4.3-9: $v_{max} = (V) / (C_o \sum L_i)$

In addition, sole plates in *Perforated Shear Wall Segments* must be anchored to resist a uniform tension force equal to v_{max}, resulting in anchorage designed for combined shear and tension.

The SDPWS-08 introduced a new design procedure that permits certain shear wall sheathing materials to simultaneously resist shear and uplift from wind forces. *Figure 2* shows a force diagram for the wall framing under combined shear and uplift. In this application, the sole plate anchorage must be designed for combined shear and tension and spaced no more than 16 in. on center to prevent sole plate splitting along the sheathing nails. Additional design and construction requirements can be found in Section 4.4.

Figure 1: Idealized Force Diagram on Full-Height Shear Wall Segment

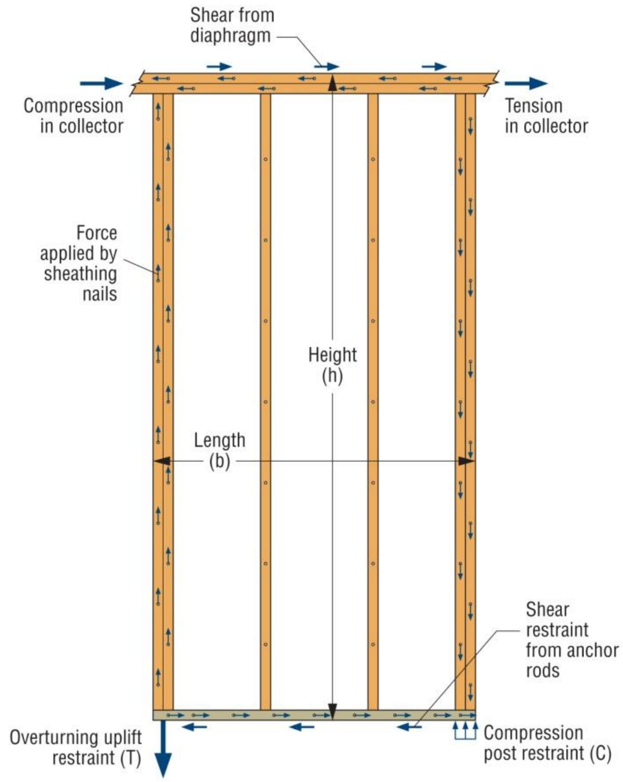
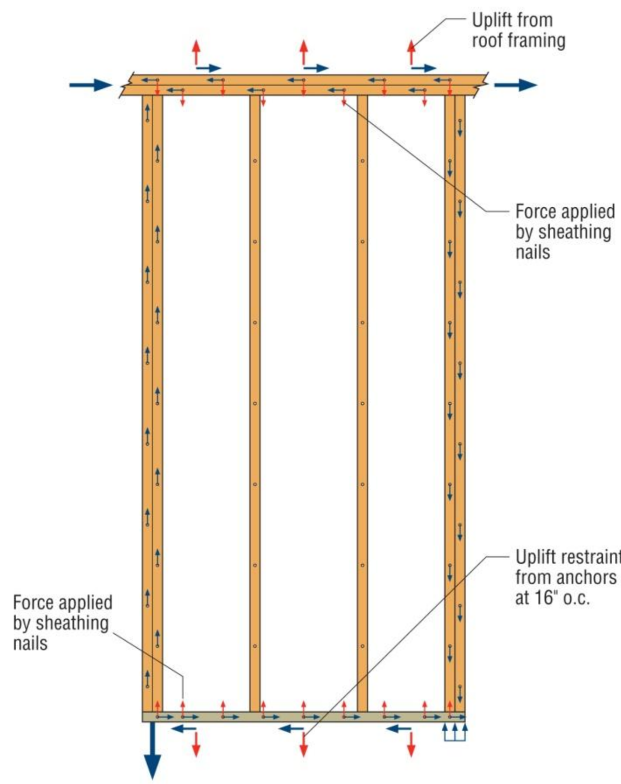


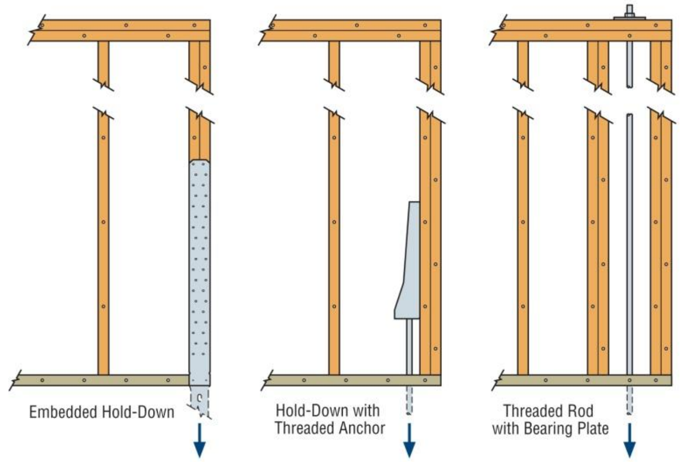
Figure 2: Idealized Force Diagram on Shear Wall Resisting Combined Shear and Uplift from Wind



Overturning Uplift Restraint

There are numerous proprietary products for resisting shear wall overturning uplift but they can generally be broken down into three types as shown in *Figure 3*: 1) embedded hold-downs, 2) hold-downs fastened to the end post and connected to a threaded anchor, and 3) threaded rods that pass through the shear wall and secure the end post down with a bearing plate above.

Figure 3: Methods of Providing Overturning Restraint



For embedded hold-downs, a new ICC-ES Acceptance Criteria was developed for code report coverage under the 2009 IBC: *Acceptance Criteria for Cast-in-Place Cold-Formed Sheet Steel Connectors in Concrete for Light-Frame Construction* (AC398). AC398 is based on a philosophy similar to ACI 318-05 Appendix D and results in separate allowable loads for cracked and uncracked concrete as well as wind and seismic forces.

Hold-downs fastened to the end post and connected to a threaded anchor are typically tested and load rated in accordance with ICC-ES *Acceptance Criteria for Hold-Downs Attached to Wood Members* (AC155). AC155 became effective in 2006 and significantly changed how hold-downs are tested and load rated by requiring additional testing on wood posts and limiting deflection to ¼-in. at the strength design level. The design of the threaded anchor into the concrete will be discussed later in this article.

Threaded rods and bearing plates used to resist overturning uplift are designed using AISC's 360-05 standard for the rod and plate components, and AF&PA's NDS-05 for bearing and bending of the wood members. Rod systems are often used in multi-story shear walls, which require special attention be paid to the effects of cumulative overturning and wood shrinkage. Shrinkage compensating devices can be evaluated using ICC-ES *Acceptance Criteria for Shrinkage Compensating Devices* (AC316). The design of the threaded anchor into the concrete will be discussed later in this article.

Sole Plate Shear Restraint

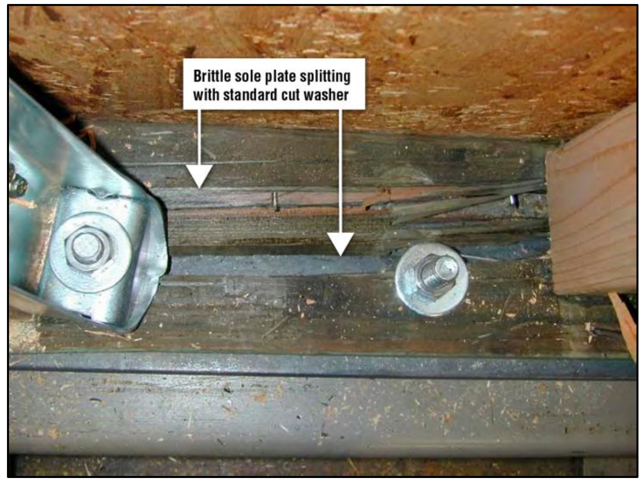
Plate washers and 3x sole plates have been used in high seismic regions since the 1997 UBC in an attempt to limit splitting along the length of the sole plate at shear-resisting anchor rods (see *Figure 4*). Recent cyclic testing has led to important changes to the sole plate and shear anchorage requirements under the 2009 IBC.

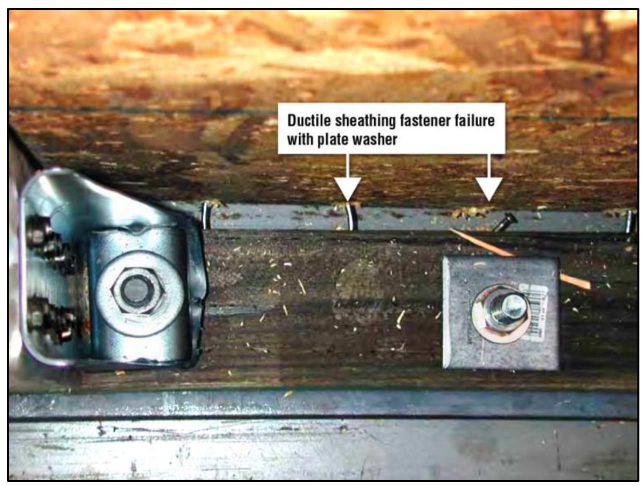
The first change deals with the size of the sole plate. Section 2305.3.11 of the 2006 IBC required the use of a 3x sole plate for certain seismic conditions. This entire section was removed in the 2009 IBC which now references the SDPWS-08. Based on tests of both 2x and 3x sole plates, the SDPWS-08 permits a 2x sole plate for all applications but requires the sheathed edge of the sole plate to be supported with a plate washer regardless of the sole plate size. This leads to the second important change.

The required use of a plate washer is no longer limited to high seismic regions. The SDPWS-08 requires the use of a plate washer for anchor rods resisting in-plane shear forces from wind or seismic loads. Based on observations from testing, exceptions are given that permit a standard cut washer for certain applications that are correlated to the strength of the sheathing assembly and the relative stiffness expected for the overturning uplift restraint. The failure limit state for low-strength, nailed wood structural panel (WSP)-sheathed assemblies tends to be ductile fastener yielding. Higher-strength, nailed WSP-sheathed assemblies can cause the sole plate to experience brittle splitting due to cross-grain bending when it is pulled up by the sheathing. This occurs when the sheathing panel rotates and is intensified when the overturning uplift restraint system permits the end post and sheathing to lift up off of the sole plate. To encourage a ductile limit state, the SDPWS-08 requires plate washers unless one of the following two conditions is met:

1. The allowable unit shear capacity of the sheathing assembly does not exceed 200 plf.
2. The foundation anchor rods are designed to resist shear only and <u>all</u> of the following conditions are met:
    a. The shear wall is an *Individual Full-Height Wall Segment* (not a *Perforated* or *Force-Transfer* shear wall)
    b. Dead load stabilizing moment is neglected when sizing the overturning uplift restraint
    c. Shear wall aspect ratio, h:b, does not exceed 2:1
    d. The allowable unit shear capacity of the sheathing assembly does not exceed 490 plf. for seismic or 685 plf. for wind (unit shear based on 7/16" OSB with 8d nails at 3" on center edge spacing into DF lumber)

Figure 4: Shear Wall Failures from Oregon State University Testing





When a plate washer is required, it must be a minimum of 0.229"x3"x3" and must extend to within ½-in. of the sheathed edge of the sole plate. Slots are permitted in the plate washer to allow for a tolerance in anchor rod placement. The 3x3 plate washer size works well with a 2x4 sole plate but when used with a 2x6 sole plate, it requires the anchor rod to be offset toward the sheathed edge and a staggered bolt pattern if the wall is sheathed on both sides. The SDPWS-08 commentary suggests simply using larger plate washers when anchor rods are centered on 2x6 sole plates. See *Figure 5* for various assembly details.

As an alternative to anchor rods with or without plate washers, anchor straps may be used when installed on the sheathed side of the sole plate provided they are approved for use in the shear wall application.

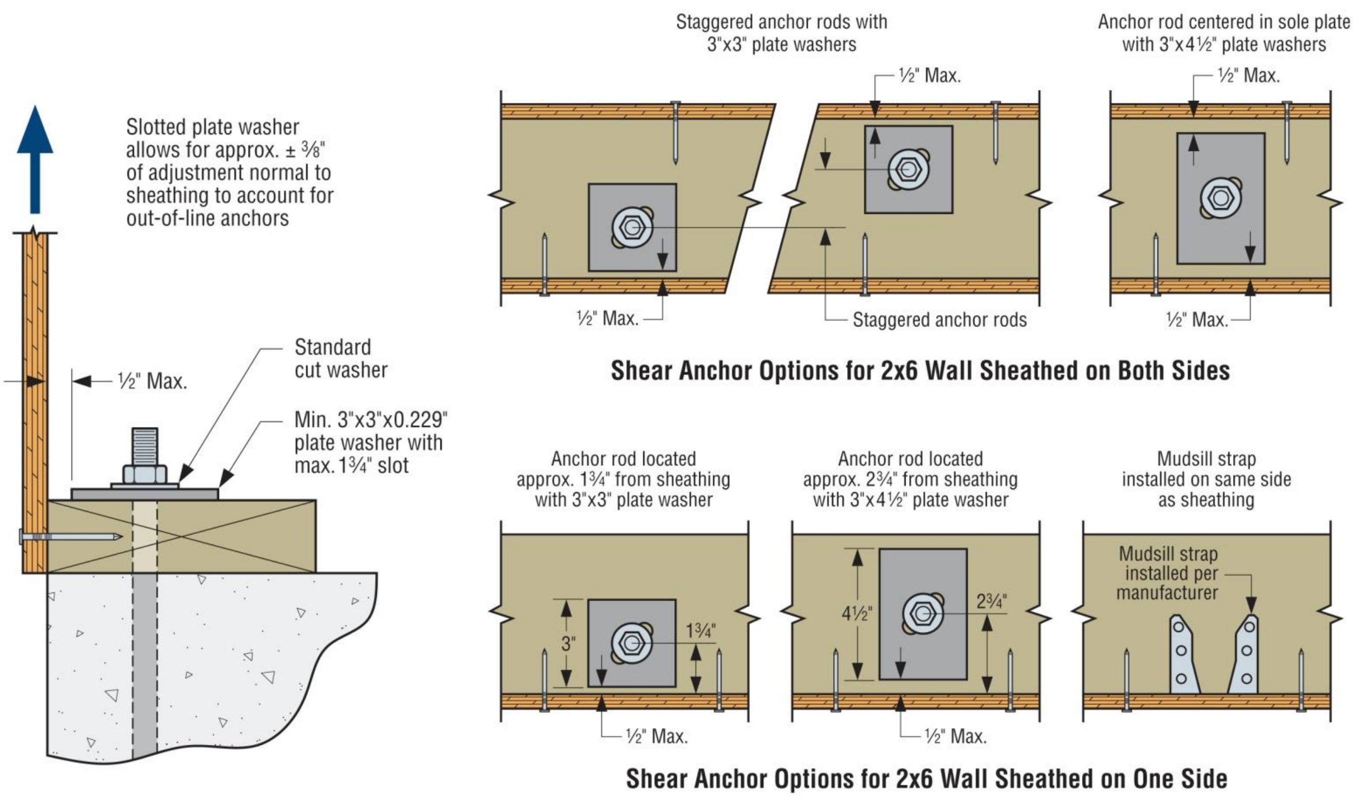
Power-driven fasteners are often used in lightly loaded shear wall assemblies. ICC-ES *Acceptance Criteria for Fasteners Power-Driven into Concrete, Steel and Masonry Elements* (AC70) limits their use to Seismic Design Categories A and B. Since AC70 does not require the fasteners to support the sheathed edge of the sole plate, power-driven fasteners are not recommended to replace anchor rods when plate washers are required.

Overturning Anchorage into Concrete

If the overturning tension force does not include earthquake loads or effects and the shear wall was designed using ASD methodology (SDPWS-08 supports both ASD and LRFD), then cast-in-place headed anchors may be designed using IBC Table 1911.2. The tabulated values in the IBC must be reduced when near edges, may be increased by 1/3 for wind when using the Alternative Basic Load Combinations of IBC Section 1605.3.2 and may be doubled when special inspection is provided (tension loads only).

If the shear wall does not qualify to use IBC Table 1911.2, then the concrete anchorage must be designed using the strength design provisions of ACI 318-08 Appendix D. A wide variety of proprietary products are available for post-installed anchors that have been evaluated using ICC-ES AC193 for mechanical anchors and AC308 for adhesive anchors. Cast-in-place proprietary bolts can be evaluated using ICC-ES *Acceptance Criteria for Cast-in-Place Proprietary Steel Bolts in Concrete for Light-Frame Construction* (AC399) and can provide high-tension capacities in near-edge conditions.

Figure 5: Plate Washer Assembly Details



Shear Anchorage into Concrete

As is the case with overturning anchor design, if the anchor force does not include earthquake loads or effects and the shear wall was designed using ASD methodology then cast-in-place headed anchors may be designed using IBC Table 1911.2 for the concrete and AF&PA's NDS-05 for the wood. Otherwise, the concrete anchorage must be designed using the strength design provisions of ACI 318-08 Appendix D.

ACI 318-08 Appendix D requires shear wall sole plate anchors that are resisting earthquake forces in Seismic Design Category C-F to be governed by either a ductile steel element or a ductile connection to the structure or have a 50% reduction in their design strength (overturning anchors face a 60% reduction). Recent testing performed by the Structural Engineers Association of California has shown most wood sole plate anchors used for shear will be governed by ductile yielding in the wood plate. The 2012 IBC will reflect this for wood sole plate anchorage (and cold-formed steel track anchorage) that meets the following conditions:

1. Shear strength of anchors is determined using AF&PA's NDS Table 11E (AISI's S100 Section E3.3.1 for CFS)
2. Anchor diameter does not exceed 5/8 in.
3. Minimum anchor embedment of 7 in.
4. Minimum anchor edge distance is 1¾ in.
5. Minimum anchor end distance is 15 in.
6. 2x or 3x sole plate (33-68 mils for CFS)

Design Methodology for Different Standards

When dealing with different material standards it may be necessary to convert design loads between Allowable Stress Design (ASD) and Strength Design (LRFD) methodologies. For example, if the wood shear wall was designed using ASD, the design loads must be converted to LRFD to design the anchorage using ACI 318-08 because 318-08 exclusively uses Strength Design. The code does not provide explicit instruction for converting loads, but engineers generally compare 2009 IBC load combination equations 16-6, 16-7, 16-14, and 16-15 to convert ASD wind loads to LRFD by multiplying by 1.6 and convert ASD seismic loads to LRFD by dividing by 0.7.

Conclusion

The 2009 IBC, material design standards and product evaluation criteria have been updated to reflect our ever-growing understanding of light-frame building performance under lateral loads. These new provisions will have an impact on the design and installation of wood shear wall anchorage. Understanding the changes and the reasons behind them will help engineers design safe, economical and code-compliant shear wall anchorage.

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