4 CONNECTIONS

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In the Shear Wall section you learned that a building must resist two types of forces: shear and uplift. The horizontal forces acting on the top of a shear wall not only create shear forces in the wall but will also create uplift forces at the ends of the wall. Tall and narrow shear walls, in particular, have a tendency to overturn due to uplift forces created when an earthquake (lateral) force pushes the top of the wall. First, we will discuss those connections used to resist uplift forces. (Fig. 4.1)

The shear wall's tendency to overturn may be resisted by its own weight or in combination with the weight of the structure above it. However, when the uplift forces exceed the given weight on or in the wall, additional resistance must be applied. This is done with the installation of metal hardware typically identified as a holdown. There are no prescriptive requirements in the Building Code for the installation of these holdowns. The engineer or architect will specify the installation of holdowns when anticipated uplift forces exceed gravity loads on the wall. Simply put, the architect or engineer specifies when the installation of a holdown is required.

Holdowns transfer uplift forces from the end of the wall through a floor to a wall or foundation below. When an earthquake shakes a shear wall back and forth, the shear wall will experience uplift forces on both ends, one end at a time. It is for this reason that holdowns are typically required on both ends of a shear wall and are connected to the end stud or post of the shear wall. The added post is better able to resist the tension load from uplift and the simultaneous compression load at the opposite end of the shear wall.

![Diagram of Uplift Force in Holdown](Fig. 4.1)
TYPES OF HOLDOWNS

Holdowns that connect a shear wall to the foundation are bolted, screwed or nailed to the end stud or added post. Retrofit holdowns are anchored to the footings using a threaded rod that is connected to the holdown. The other end of the rod is adhesive set into a hole that is drilled into the foundation concrete. This rod transfers the uplift force from the wall down into the foundation. This minimizes the wall’s tendency to overturn.

Holdowns that connect two walls through a floor come in pairs; one above and one below. The holdowns are bolted, screwed or nailed to their respective end stud or added post. The uplift forces are then transferred from the wall above to the wall below through a threaded rod that is bolted to the holdowns. (Fig. 4.2)

Similar to bolted holdowns, metal straps can be used as holdowns to connect the end studs or added posts below the floor. The strap must be long enough to pass through the floor framing and be attached to the end studs or added posts so that the required number of nails or bolts are provided between the strap and the end stud or added post both above and below the floor. The strap should also be taut and straight to reduce slippage (Fig. 4.3).

IMPORTANCE OF PROPER INSTALLATION

To better understand the importance of properly installed holdowns, consider a tall and narrow shear wall that is 8 feet tall and 2 feet 3 inches wide (height to width ratio of 3 ½ to 1). By applying an earthquake induced horizontal load at the top of the wall, the wall will begin to overturn. For every one inch that the bottom, left corner of the wall goes up, the upper, right corner will move laterally a distance of 3 ½ inches.

Cyclic testing of wood shear walls has shown that lateral movement of as little as 2 inches can cause loss of vertical support and therefore, cause building collapse. Accounting for the height to width ratio of 3 ½ to 1, this means that if a holdown at the bottom left corner of a shear wall slips as little as 5/8 inch up, the building could suffer significant damage and possible collapse!

Proper installation becomes even more critical when you consider that even a properly installed holdown will tend to allow some upward movement. This inherent deflection can be attributed to:

1. Localized crushing of the wood fiber around the fasteners
2. Crushing of the sill or sole plate under the end stud.
3. Stretching of the metal holdown hardware.
4. Random nut spin or thread stripping during the earthquake.
5. Bending of the fastener (nail, screw or bolt)
6. Wood shrinkage
7. Additional rotation allowed from one-sided connection

Proper installation is essential. (Fig. 4.4) A number of things can go wrong when installing holdowns. What follows is a discussion of some of the more common problems and how to avoid them.
COMMON HOLDOWN INSTALLATION ERRORS

Holdowns should be installed as specified on the plans and following the manufacturer’s installation instructions. Substitutions of holdown hardware require the prior approval of the building department and the design professional (engineer or architect). An errant substitution may not provide the same resistance to uplift as originally intended.

When new holdown posts are specified, such as a 4x4 or 4x6, you should not substitute the specified post with a doubled stud. The allowable strength of a holdown is partly based on the cross-sectional area of the end stud. The strength of the holdown is generally reduced by attaching it to two 2x studs (3 inches) instead of the specified solid post (3 ½ inches). (Fig. 4.5)

When nailing on straps used as holdowns, the minimum required edge distance must be maintained. The minimum required edge distance depends on the size of nail used. Nails should be installed no closer to the edge of the wood member than ½ the minimum required embedment depth of the nail (see Table 23-G of the Uniform Building Code). For example, if the nail’s minimum embedment depth is 1-3/4 inches, the nail should be installed no closer than 7/8 inch from the edge of the wood member. (Fig. 4.6)

Shear wall end studs or posts should normally be one full piece for the height of the wall. This is necessary because the end stud or post must be capable of resisting tension due to the uplift forces. Otherwise, additional connections will be needed inside the wall to transfer the uplift forces.

When plans specify the installation of new posts in an existing or new wall, the posts should be installed at the ends of the wall. As you now know, tension or uplift loads occur at the ends of a shear wall. Unless otherwise approved by the engineer or architect, holdowns should be located as close to the ends of the shear wall as practical. (Fig. 4.7)
INSTALLATION ERRORS FOR BOLTED HOLDOWNS

- **Improper End Distance**

With respect to the holdown location on the post, the bolts attaching the holdown to the post should be located per the manufacturer’s installation instructions. In general, the first bolt should be at least seven bolt diameters from the bottom of the post. This minimizes the chances of the bolt ripping right through the end of the post during an earthquake (Fig. 4.8).

- **Oversized Bolt Hole**

The post bolt holes must not be oversized. If the hole is bigger than the bolt, the bolt will move before it engages the wood and will be much more likely to split the post. The building code allows the hole in the end stud to be a maximum 1/16-inch oversized. The proper drill bit size must be used so that the hole is no larger than 1/16 inch bigger than the bolt diameter (Fig. 4.9).

- **Undersized Washers**

In addition, washers should always be used where the bolt head or nut bears directly on wood. This typically occurs on the post side that is opposite the holdown. Square plate washers should be used instead of round malleable washers. This will help better prevent the bolt pulling through the end stud during an earthquake (Fig. 4.10).

- **Substitution of Lag Screws for Through Bolts**

When through bolts are specified, lag screws should not be used. A lag screw, even if it is the same diameter, will not have the same strength as a through bolt.

- **Countersinking Nut & Washer**

Post bolts should never be countersunk into the post unless the installed post is at least one size larger than that specified. For instance, if the plan calls for a 4x4 post and it becomes necessary to countersink the bolt head, a 4x6 post should be used. This allows for an additional 2 inches of post thickness in which to countersink the bolt head (Fig. 4.11).
• **Insufficient Depth of Embedment for Anchor Rods**

Holdown rods anchored into the foundation should be embedded as required by the manufacturer or structural design. The rods should only be embedded into sound concrete or reinforced masonry. Unlike a typical anchor bolt, the holdown rod must resist uplift forces. The loads imposed on a holdown rod are generally greater than those imposed on a typical shear wall anchor bolt. Holdown anchors that are not installed to the proper depth and at the minimum edge distance will not perform as intended during an earthquake (Fig. 4.12).

![Fig. 4.12 Lack of Embedment for Holdown Anchor](image)

• **Substitution of Holdown Anchor Type**

Wedge or Expansion type anchors should not be substituted when chemical (adhesive) anchors are specified. For holdowns, these anchors do not generally perform as well as adhesive anchors during the cyclic uplift loading caused by earthquakes.

• **Untightened Nuts**

The nut must be tightened securely on the holdown rod. If not properly tightened, the wall will begin to uplift during an earthquake before it engages the holdown. This movement can split both the sill plate and the holdown post. When the nut is not properly tightened, shear wall overturning will cause damage to the building (Fig. 4.13).

![Fig. 4.13 Untightened Nut Found in Earthquake Damaged Building](image)
CONNECTIONS RESISTING SHEAR FORCES

A typical wood-framed building has many connections where shear forces are present. All of these connections are links in the shear load path. Just as with the uplift forces, these shear forces must be adequately resisted in order to minimize building damage (Fig. 4.14). No matter how heavy the gravity load, friction alone is not an effective way to create a load path. Remember that the heavier the gravity load, the greater the inertia and resulting shear force.

Two pieces of wood that are butted together can be easily pulled apart if not connected by some type of splice. Similarly, two pieces lying one on the other can be slid past each other if not properly connected (Fig. 4-15). In wood framing, all connections need to have a nail, screw or bolt connecting two pieces together. Proper shear connections are created with combinations of fasteners, blocking and hardware such as framing anchors.

FASTENER TYPES IN SHEAR CONNECTIONS

For nailed connections to be effective, the nails need to penetrate the wood a minimum depth. To accomplish this, the specified nail length must be used in all wood connections. It is also important to use the proper diameter nail (common vs. box) and avoid splitting the wood while nailing.

Screws should not be randomly substituted for nails. While screws provide superior holding power in tension, they have reduced ductility. Ductility is necessary to prevent brittle fracture during cyclic loading. Always consult the architect/engineer and the local building official when considering this substitution.
There are many breaks in the continuity of a conventional platform-framed building, particularly if it rests on cripple walls. Shear forces created by the earthquake must be effectively transferred through these breaks in order for the load path to be complete. The following elements must connect to each other to develop this complete path.

1. Roof and ceiling must be attached to the top plate(s).
2. Top plate must be attached to the sheathing.
3. Sheathing must be attached to the sole plate.
4. Sole plate must be attached to the floor framing.
5. Floor framing must be attached to the top plate(s).
6. Top plate(s) must be attached to the sheathing.
7. Sheathing must be attached to the foundation sill plate.
8. Foundation sill plate must be attached to the foundation.

When these elements are properly connected, they form an unbroken load path from the roof and floor diaphragms to the ground. Figure 4-16 shows forty-four (44) elements in this shear load path.

When evaluating an existing building for possible retrofit, it is important to identify non-standard framing. Balloon framing is one type of non-standard framing. Balloon framed structures were common on the East Coast and Midwest until recently. Some older buildings on the West Coast are also balloon framed. In balloon framing, the intermediate floor framing joists are face nailed directly to the studs. The studs are continuous from top to bottom of the building. This creates a load path discontinuity between the floor diaphragm and shear wall. When encountering this or any other type of non-standard framing, an architect or engineer should be consulted. (Fig. 4-17)
CONNECTIONS AT TOP PLATES

Walls built today usually have doubled top plates on which the roof, ceiling or floor framing above rests. On some older buildings, only a single top plate was installed. The top plate(s) is where the shear wall sheathing is nailed and where the shear forces transfer from the roof, ceiling or floor diaphragm. For adequate transfer of forces, it is necessary to attach the top plate to the rim joist or blocking above.

Code conventional framing requires that each joist be attached to the top plate with 3-8d toenails. This amount of attachment may not be adequate for shear forces in the plane of the wall. Since it is difficult to determine if there is sufficient existing toe-nailing, metal right angle clips (framing clips) should be nailed into the top plate(s) and the rim joist or blocking. This will strengthen the shear connection between the floor framing and the shear wall below. (Fig. 4.18)

These shear connections should be installed at the required spacing along the entire length of the wall. Spacing will depend on the given design value of the clip and the prescriptive or engineered retrofit design that is being used. For shallow 2x6 or 2x8 joists, it may be difficult to attach the clip into the rim joist or blocking and top plate. The use of a pneumatic palm nailer will make this installation easier in difficult access areas. (Fig. 4.19)

Splices in double top plates should be properly lapped and the laps should be well nailed. If a double top plate is notched or cut (say for a plumbing vent), metal straps should be added across the notch to restore its tension capacity. When splices of double top plate are not properly built or if there is only one discontinuous top plate, a metal strap should be nailed across the splice to provide the necessary continuity. (Fig. 4.20)
CONNECTIONS AT SOLE PLATES

At the bottom of a shear wall, the attachment of the sole plate and the floor decking to the floor framing accomplishes the shear transfer from the shear wall and the floor diaphragm to the floor framing below. When nails or lag screws resist shear, they must be sufficiently long enough to penetrate through the sole plate and floor sheathing into the framing member below. (Fig. 4-21)

For full load values, Table 23-G of the Uniform Building Code specifies the minimum penetration required of nails into the framing member. When the nail penetration falls below Table 23-G values, the allowable load for the nail is reduced proportionally up to 50% of its value. When nail penetration falls below 6 nail shank diameters, the allowable load value is zero. For this reason, nails often cannot transfer shear forces through thick sheathing.

If the wall framing is exposed above the floor, as in new framing that has not yet had plaster or drywall attached, the nails can be installed from above. However, in some retrofit situations, the wall framing above is not (or cannot be) exposed. In this case, it may be possible to add framing clips where the underside of the floor and the rim joist or blocking meets. Short joist hanger nails should be used to attach the clips to the joist or blocking. Longer nails or wood screws should be used to penetrate up through the floor decking and into the sole plate above.

In some multiple story buildings, double sole plates may be encountered. The second sole plate may have been installed to act as a form for poured-in-place lightweight concrete or gypsum sub-floor material. Where this occurs, it is important to maintain a load path through both plates. In new construction, this is accomplished by nailing the first sole plate and second sole plate with a sufficient number of nails specified by a design professional. In existing construction, it may be necessary to use extra long nails or screws through both plates so that the fastener has enough penetration into the framing member below. (Fig.4.22)

Another way of accomplishing the shear transfer from a wall and floor above into the wall below is to use longer sheets of wood structural panels. By spanning full sheets from the rim joist or blocking above to the rim joist or blocking below, the panel serves as a direct load path from one shear wall to the other. This reduces the number of links in the chain and eliminates the need for framing clips. Remember to install the four rows of nails (as illustrated) to provide a load path from the floor diaphragm as well as the wall above and always provide the recommended gap between panel edges to allow for expansion. New construction requires even larger gaps for shrinkage of the rim joist or blocking. (Fig. 4.23)
CONNECTIONS AT SILL PLATES

Because shear loads are cumulative as they work their way down a building, they are greatest at the base of a building. Shear loads are transferred from the shear wall into the foundation through the sill plate. Consequently, the sill plate must be attached to the foundation with anchor bolts or plates. Before the load enters the anchor bolt or plate, it must successfully pass through the sill plate. Sill plates should be in good condition and free from cracks. If a cracked or split sill plate is encountered, it should be replaced before proceeding with the retrofit (Fig. 4-24).

Sometimes existing anchor bolts in the sill plate are too few in numbers or size or are rusted through under the sill plate. Some older buildings did not bolt their sill plates to the concrete stem wall. In these cases, special retrofit anchors must be used to strengthen the sill plate connection. New sill plate anchors are installed in two ways: drilled-in anchors through the sill plate or side plates that connect the sill plate to the foundation concrete or masonry. Side plates are used when there is not enough room to stand a drill motor on top of the sill plate (Fig. 4.25-27).

Drilled-in anchors come in two types: mechanical and adhesive. Adhesive anchors have the advantage of working in lower strength existing concrete. They are more expensive to install than mechanical anchors and require greater quality control during installation. Mechanical wedge anchors are easier to install but require generally greater concrete strength due to the concentration of stresses at the expansion clip. When sufficient concrete strength exists, either adhesive or mechanical anchors may be used. Generally the strength of both anchor types in concrete is greater than their strength in the wood sill plate.

All anchoring products should be installed per the manufacturer's installation instructions. Some products require special inspection as defined in Chapter 17 of the Uniform Building Code. Always check with the manufacturer and the local building official to determine if special inspection is required.
LOCATING DRILLED-IN ANCHORS

• Provide Proper Edge Distance in the Concrete and Wood

Drilled-in anchors require a minimum edge distance in concrete. The manufacturer’s recommendations will specify the minimum amount required for each diameter anchor. Anchors without sufficient edge distance will fail in earthquakes and sometimes, even during installation (Fig 4.28). When obstructions require the hole be drilled at slight angle, make sure that the bottom of the hole still has the minimum edge distance. This is particularly important when using mechanical anchors. Normally, drilled-in anchors should be installed near the center of the sill plate (Fig. 4-29). This will furnish the minimum required $1\frac{1}{2}$ bolt diameter edge distance in the wood. For 2 x 6 sill plates, this will generally provide adequate edge distance in the concrete.

When foundation walls of a house are located slightly out of position, builders will sometimes adjust the wood wall location. They do this by partially overhanging the sill plate at the edge of the foundation wall (Fig. 4-30). If such a condition is encountered during retrofit, an architect or engineer should be consulted. If the overhang is severe or the required edge distances in the concrete, masonry or wood is not provided, a special repair or connection may be needed to effectively transfer the shear loads.

• Provide Proper End Distance in the Sill Plate

Additional anchors should be installed within 12 inches but not closer than 7 bolt diameters from the end of each sill plate piece.

AT CORNER  AT INTERSECTION  AT SPLICE

Fig. 4-29 Proper End Distance for 5/8-inch Sill Plate Anchors

• Provide Proper Depth of Embedment in the Concrete

To safely resist their shear loads, both adhesive and mechanical anchors need a minimum depth of embedment in the concrete. The manufacturer’s recommendations will show the minimum embedment depths required. When holes are drilled deeper than required, nuts and plate washers should be installed on the mechanical and adhesive anchors before they pass through the sill plate. This will prevent the anchor from sinking too deep into the hole. If the anchor settles too deep in the hole, it should be left in place and another anchor installed nearby. When plate washers and nuts are countersunk into the sill plate, the reduced plate thickness weakens the connection (Fig 4.31).
• **Use the Proper Length of Anchor**

When edge distance permits, drilled-in anchors can be installed directly through the blocking added for cripple wall strengthening but longer anchors are needed to provide the minimum depth of embedment in the concrete. Longer anchors are also required when sill plates are full two inches thick. This commonly occurs in older buildings (Fig. 4.32).

![Fig. 4.32 Sill Plate Anchor Options](image)

• **Use Plate Washers**

To further reduce the chances of the sill plate splitting during an earthquake, square plate washers should be used instead of round washers. Round malleable washers tend to fold up and split the sill plate during an earthquake, especially when the sill plate hole is oversized. During the 1994 Northridge earthquake, sill plates often split or pulled through anchor bolts. The square plate washer is more effective in creating a good friction connection between the sill plate and the bolt. It also makes tightening of expansion anchors easier (Fig. 4.33).

![Fig. 4.33 Square Plate Washer](image)

**INSTALLING MECHANICAL ANCHORS**

Mechanical anchors attach to the concrete through friction by mechanically expanding or wedging against the concrete. These types of anchors are effective if the concrete is in good shape and the minimum edge distance is maintained. The proper diameter hole is essential to allow the anchor to properly engage. Normally it is the nominal diameter of the anchor. Sometimes the bolt will not engage due to air or powder pockets in the area of the expansion wedge. This will be apparent when the bolt will not torque to the required strength. When this happens, the bolt should be abandoned and a new bolt should be installed nearby in a new hole.

Wedge anchors have a required torque to properly set them in concrete. For sill plate anchors, the range is generally 50-120 ft-lbs. The use of plate washers will help reach the required torque without excessive compression of the sill plate under the washer. Follow the manufacturer’s recommendation for the required torque and use a calibrated torque wrench.
INSTALLING ADHESIVE ANCHORS

- **Carefully Clean the Hole**

Unlike mechanical anchors, adhesive anchors attach to the concrete chemically; they glue to the concrete. These products usually come in a two-part tube applicator and are readily available. Because the products create a chemical bond between the anchor rod and the concrete, it is extremely important that the hole be properly drilled and cleaned. The product must adhere directly to the concrete surface and not to residual dust that might be left in the hole after drilling. Carefully clean the hole as required by the manufacturer. The hole must be properly brushed and blown out prior to adhesive installation (Fig. 4.34 & 4.35).

- **Use All-threaded Rod**

Although these products chemically bond to concrete, they will NOT chemically bond to the anchor rod (steel). Therefore, threaded rod is required for all adhesive-anchoring systems. This allows the product to engage the threads and create a good mechanical bond to the rod.

- **Completely Fill the Hole in the Sill Plate with Adhesive**

Most adhesive products require holes in the concrete that are oversized 1/8-inch larger than the all-thread diameter rod. This creates oversized holes in wood sill plates because the limit is only 1/16-inch. To remedy this, enough adhesive should be placed in the hole to overflow the sill plate once the rod is installed. This will allow the sill plate to immediately engage the anchor rod during an earthquake and allow it to transfer shear forces directly into the rod, thus reducing the chances of the sill plate splitting (Fig. 4.37).

- **Install the All-thread Rod with the Plate Washer and Nut Attached**

The washer and nut should be placed on the rod prior to installing the rod since the adhesive extruding from the top of the sill plate will make it difficult, if not impossible to install the washer and nut at a later time.

- **Wait Until Fully Cured Before Tightening**

Adhesive anchor installations will need to cure for several hours before they can be tested. Always check manufacturer’s requirements for minimum set and cure time. The time will vary depending on the product used and the temperature.

- **Follow Safety Requirements**

A final word of caution on the use of adhesive anchors: you need to protect workers and the people living in the building from the fumes. Check with the manufacturer to find out which product is appropriate for the use and what precautions will be needed. You will learn more about this in the section on Safety & Legal.
INSTALLING SIDE PLATES

When installing these plates, follow the manufacturer's installation instructions carefully (Fig. 4.37). Unless otherwise approved, lag screws require pre-drilling to avoid splitting the sill plate during seismic loading. Lag screws require pre-drilling even if you intend to use a pneumatic wrench. Be careful not to overtighten the lag screw during installation. This will strip out the hole. To prevent damage to the hole, never drive the lag screws with a hammer.

Lag screws require two different diameter pre-drill holes. The larger diameter pre-drill hole is for the solid shank portion of the screw. This hole should be drilled the same diameter as the screw itself. The second hole is the pre-drill hole for the threaded portion. This hole must be smaller than the threaded diameter in order for the lag screw to grip the wood. Required pre-drill hole sizes for both lag screws and nails are shown in the Appendix.

INTERIOR POST TO GIRDER CONNECTIONS

There is a misconception that the strength of the crawl space can be increased by adding gussets, straps, or bracing to the interior posts. In a house with a properly braced perimeter cripple wall, elaborate post connections will not provide any benefit. The posts need only a simple toenail connection at the top and bottom to keep them from shifting during an earthquake (Fig. 4.38).

When seismic strengthening is being performed in the underfloor crawl space, you should inspect the post connections and provide toenails, small straps, or clips only when there is no existing connection. When you are unsure about the condition, have an engineer evaluate it. If the perimeter of the house is properly braced, there should be very little movement at the top of these posts.

PUTTING IT ALL TOGETHER

By carefully following the plans and the manufacturer's specifications and installation instructions, and by following these tips and guidelines, you will significantly reduce the number of weak links in the load path chain. When installing a retrofit, understand the objective. By understanding the load path and realizing the importance of maintaining a complete and continuous load path from top to bottom, you will be able to complete a more effective and possibly a more economical retrofit.