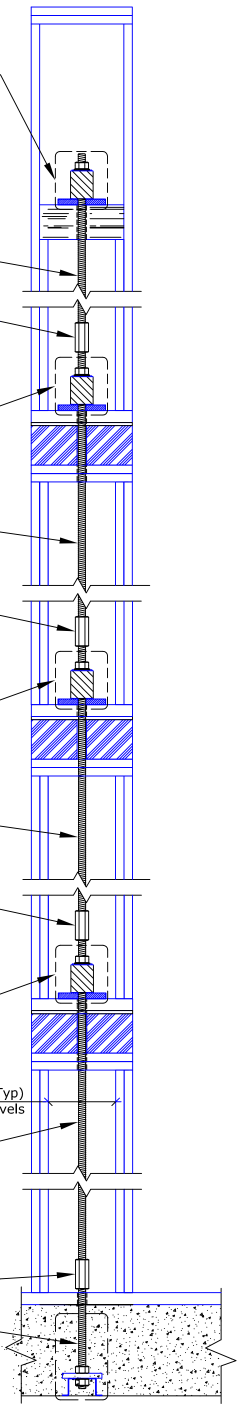
Typical System



Tie-Down Systems-Designing to the Code

Recent changes by ICC ES require designers to revise the tie-down system design method. The requirements have always been there, but revised ICC-ES Acceptance Criteria specifically require certain strength and elongation limits and define required items to be considered. This section provides important background information on components, elongation limits and wood shrinkage.

ICC-AC 316

In June 2012 ICC-ES established guidelines for tie-down system elongation restraining shear walls. AC 316 added the following amendment:

> "6.9 Shear wall drift limit shall consider 0.200" displacement per story or between restraints. The 0.200" displacement may be exceeded when it can be demonstrated that the shear wall story drift limit and the deformation compatibility requirements of IBC section 1604.4 are met when considering all sources of vertical displacement."

Systems approved under AC 316 shall comply with this requirement by April 1, 2013.

Why do we have this new limit?

The IBC specifies allowable shear wall drift limits using the following equation:

$$\delta_{sw} = \frac{8vh3}{EAb} + \frac{vh}{1000G_a} + \frac{h\Delta_a}{b}$$

In 2008 the SEAOC seismology committee reviewed this equation and noted that under certain circumstances the shear wall may receive 83% of the allowable drift from hold-down deformation alone. (Note: this was the "da" in the previous four part equation and is now **Δa**). Based on their analysis, looseness introduced by the hold down system could result in excessive wall drift and mud sill splitting.

Note: the SEAOC analysis did not address wood shrinkage or building settling and did not include multiple tie down components. The SEAOC analysis included **only** the tie-down itself. Multiple tie-down components coupled with building shrinkage can radically degrade shear wall performance.

Why is the Limit Set at 0.200"?

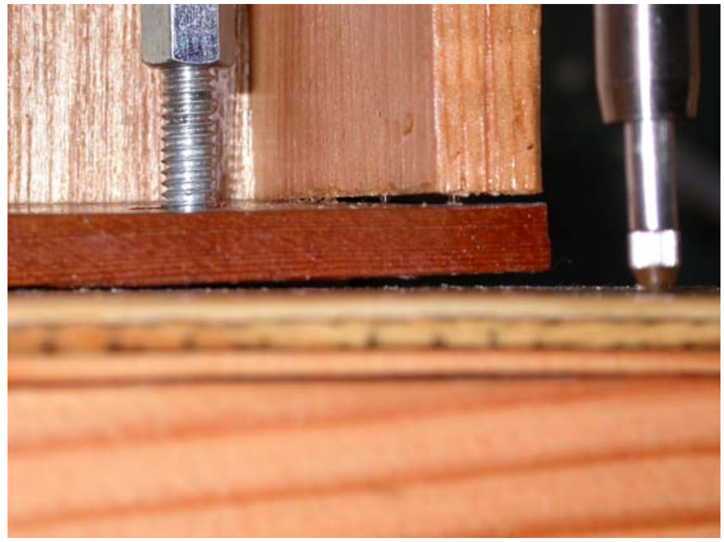
Cyclic testing of light frame shear walls has demonstrated that 0.200"looseness in a shear wall will degrade lateral performance as much as 40%. Observers have noted nails begin failing in the plywood when uplift approaches 0.100". Because of these observation's a number of jurisdictions have established elongation limits ranging from 0.125" to 0.200". Additionally, engineers who have examined the problem have established firm limits of 0.200 or below. Based on input from the engineering community ICC ES has established the 0.200" limit.

For a typical code shear wall with a height to width (or breadth h/b) ratio of 1 or less the 0.200" uplift limit makes sense. But if we look at the shear wall drift equation above note that if the wall is short the contribution to overturning of the tie-down system is excessive, so while the uplift limit is required to be at or below 0.200", shear wall drift may require an even lower limit. A lower limit may also be needed to minimize mud sill damage and to allow shear wall drift compatibility.

Tie-Down Systems

Building Damage Noted after Earthquakes

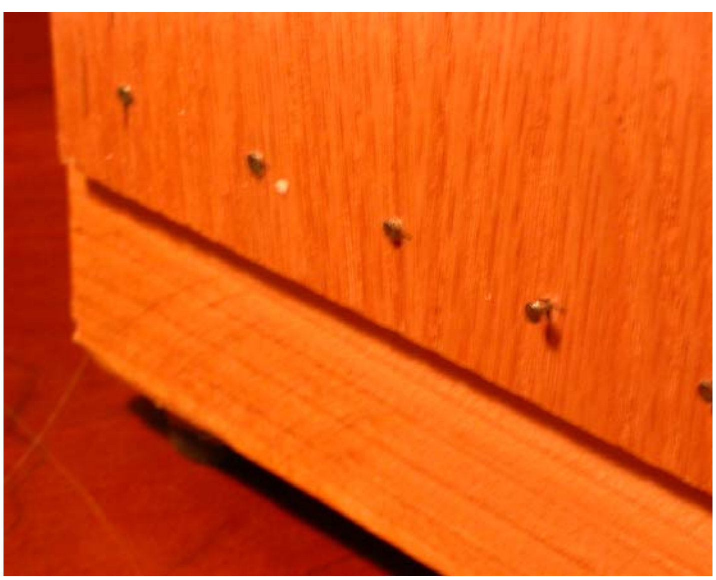
After the 1994 Northridge Earthquake researchers noted " vertical tie-down looseness due to inadequate tightening of nuts" and cross-grain splitting of mud sills due to "inadequate sole plate washers".



The looseness of the connections was certainly there along with the failed mud sills but I ascribe the failures to shrinkage, settling and stretched holdown systems. And, regardless of the size of the sole plate washers, a loose tie-down that allows the wall to rotate will stretch and bend the mud sill, destroying the mud sill and the shear wall nails attaching the sheathing to the mudsill. The photo at the right demonstrates the initial looseness and associated movement in a demonstration model

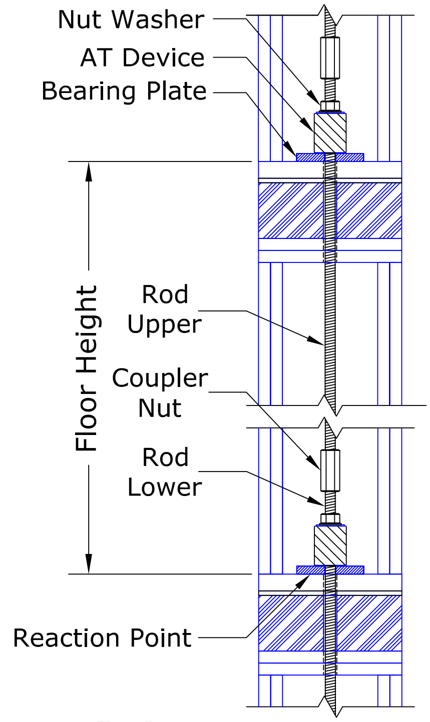
I have designed, tested and evaluated hundreds of shear walls and tie-down systems. The testing included both monotonic and cyclic protocols. Tie-down system elongation that allows a mudsill to lift 3/16" to 1/4" often leads to a cross grain bending mudsill failure. Others have observed that when a lateral load forces the mudsill to lift over 0.200" the mudsill often splits. A split mudsill can quickly destroy the performance of the wall.

Mudsill splitting can be demonstrated on a model. Looseness is introduced by backing off the nut at the top of the wall (typical of building shrinkage) and applying a lateral load. Mudsill bending is quickly observed. When tie-down looseness exceeds a certain amount the mudsill will twist. Mudsill twist imposes cross grain bending and progresses to a split. Note: the loose connection is the main source of mudsill splitting. A large mudsill washer can't solve this problem. The only real solution is a tight, low deflection connection. With a wood building this tight connection requires either dry wood (with a MC of 10% or so) or a shrinkage compensating device.

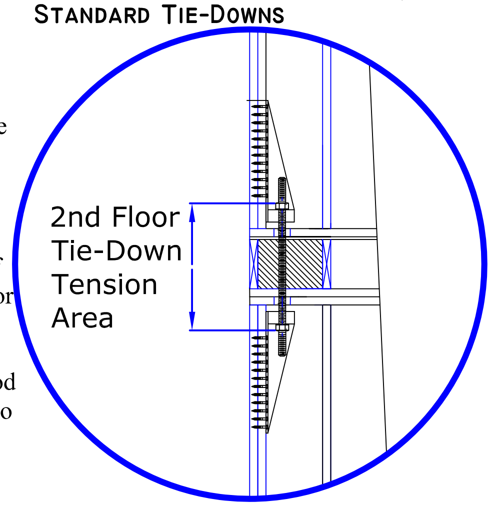


After several cyclic load reversals the nails attaching the shear panel begin to pull out or pull through.The photo to the left demonstrates the effect on nails that results from a cyclic load on a loose shear panel.

Tie-Down Components



STANDARD TIE-DOWNS



Proper evaluation of tie-down systems requires all system components must be fully specified. If any item is left out the analysis is flawed. A complete analysis must include system strength and elongation.

System Components can include threaded rod, bearing plates, shrinkage compensators, washers, nuts, and couplers. In addition, shrinkage/settling is considered an elongation "component". For a given connection not all components are needed, but if used they must be analyzed. Shrinkage and settling should always be included. If a shrinkage compensator is used the amount of shrinkage compensation must be known. If a shrinkage compensator is not used, the shrinkage amount must be added to system elongation.

Threaded rod strength is analyzed per AISC 360, equation J3-1. Or may be take directly from AISC table J3.2 (p16.1-104). Elongation is calculated per AC391 3.2.1.1. A shortcut design method is to pre-calculate the elongation of 10' rod at the rod design capacity. A look-up table lists strength capacity and the elongation for 10' of rod. An inspection of the table then provides both allowable strength and elongation information. The rod elongation is ratio of the actual length/table length times actual load/listed load.

Bearing Plates To transfer loads into the structure either hold downs or bearing plates are used. Bearing plates are sized and load rated per AC 391 and NDS 2005. The allowable load on a bearing plate is defined as the load that deflectsthe plate 0.040".eflection is adjusted by the ratio on actual/allowable load

Hold-downs (tie-downs) are load rated per AC 155. Deflection is adjusted by the ratio of actual/allowable loads. **Note:** if two hold-downs are used in series (example to bridge a floor) the deflection of this component is doubled.

Shrinkage/Settling is a system component. Shrinkage is considered elongation without load. If shrinkage is low (1/16"-1/8") a shrinkage compensator may not be needed. If shrinkage is greater than 1/8" a shrinkage compensator should be used. Typically, engineers design for 1/4" to 1/2" of shrinkage per floor. Note: a properly applied shrinkage compensator should eliminate the need for a precise shrinkage calculation.

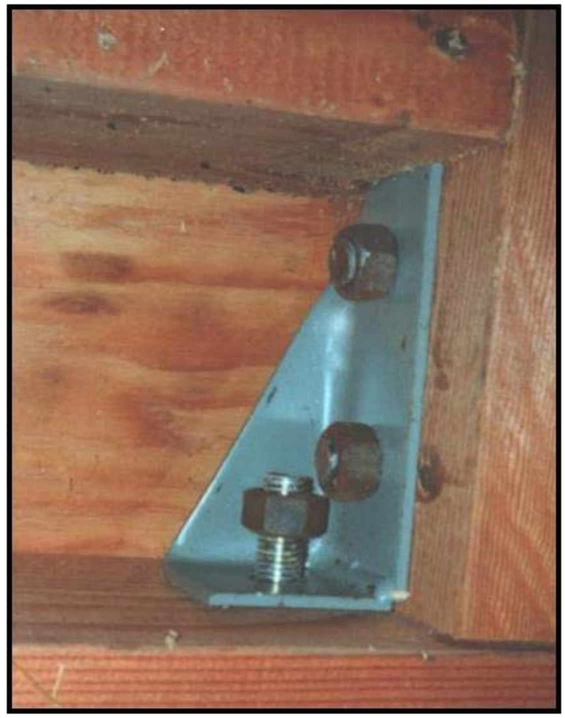
Shrinkage Compensators (also known as Take-Up Devices or TUDs) are rated by AC316 for rod size (fit), load capacity, deflection and shrinkage capacity. Deflection (**ΔA**) is adjusted by the ratio of actual to allowable loads.

Shrinkage Compensators also have another property called delta R (ΔR). Delta R looseness is the average travel and seating increment. Delta R is not a function of load rather is a fixed attribute of the TUD. This movement is part of, and must be added in full to, system movement. Therefore shrinkage compensator total movement = $\Delta T = \Delta A + \Delta R$ (Note: ΔR must be used in full whereas ΔA may be load adjusted)

Significance

Delta R (ΔR) for shrinkage compensating devices varies from 0.000" to 0.080". System elongation consists of the sum of rod, bearing plate and shrinkage compensator deflections. If the system limit is 0.200", staying within this limit may require enlarging the rod and/or bearing plates to limit the elongation.

Shrinkage



The building industry has addressed wood shrinkage with better products and better packaging. Today we can buy wood joists made from green wood with a moisture content (MC) of 30%, Kiln Dried wood with an MC of 19% and Manufactured Wood (I-Joists, Paralam etc.) with a MC at or below the equilibrium moisture point.

To estimate wood shrinkage a large number of variables must be considered. Required information includes starting MC of the mudsills, and joists; the equilibrium MC of the building; the "stack height" of the wood; the wood species, and the grain orientation. Then we should ask the question "should we consider average shrinkage or worst case shrinkage?" Finally, will a shrinkage compensator be used?

Shrinkage/Settling In May 2008 the SEAOC committee noted building settlement, excessive moisture content, sill plate crushing and slip or looseness within various shrinkage compensating devices, but they didn't address these sources or attempt a resolution.

The photo on the right was taken in Mendocino County; California in 1999. The building was 12 years old. About 12 hold-downs were installed. In every case the tie-down bolt showed 5/8" to 3/4" of looseness. This building was built with "wet" wood. The shrinkage demonstrated 12 years of shrinkage in a "dry" coastal environment

Multi-Story Shrinkage

The photo at the left is from a 5 story building in Seattle. The floor system consists of wood "I" Joists and solid sawn plates. The walls were opened because of a moisture problem When the tie-down system was investigated every floor demonstrated 1/4" to 3/8" of shrinkage. The connector shown is part of a multi-story tie-down system. Under uplift loading this looseness will be transferred to all floors connected above. For example, should the top floor lift, all floors below will contribute to the looseness. We could see four floors x 3/8" looseness or 1-1/2" of movement before the wall is restrained.

Straps

Metal straps are used ubiquitously for vertical connections in wood construction. Some builders refuse to use them at all, while others nail the top portion and wait 6 months to a year to nail the bottom. (Obviously most builders have to work somewhat faster). Building shrinkage results in bowed straps.

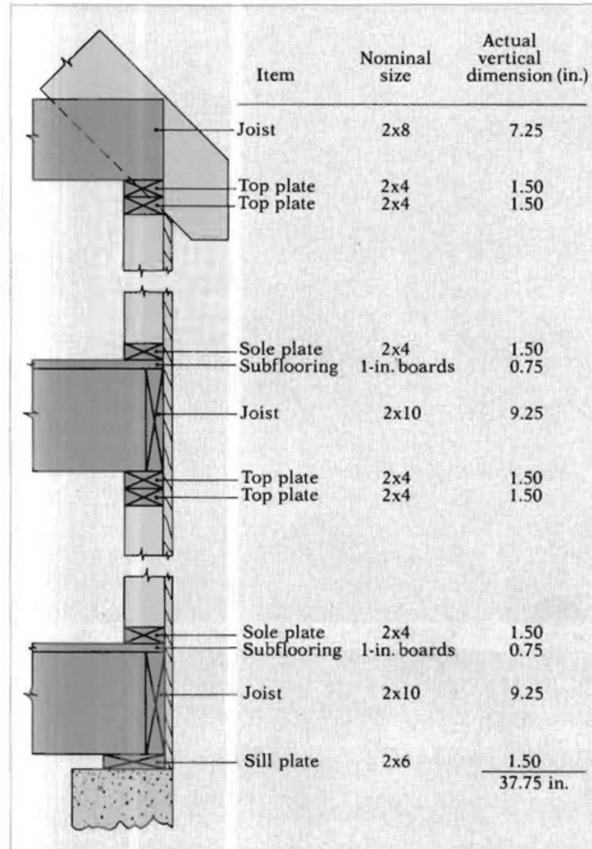
We recommend against the use of vertical metal straps.

Published Wood Shrinkage Information

Understand wood shrinkage and building settling is key to understanding and predicting shear wall and ultimately building performance. The following is a quick overview of some available information.

In his book ***Understanding Wood***, R. Bruce Hoadley takes and in-depth look at wood building shrinkage. The example at the right uses a total wood "stack height" of 37.75" and estimates the two story shrinkage to be 0.782". This example uses "dry" wood. Mr. Hoadley then estimates that if green lumber were used the shrinkage would be twice as great or about 1-1/2". Note: this is a 2 story building.

If the same approach is used for tie-downs across a 10" floor, the "stack height" is about 14-1/2". The calculated shrinkage is about 0.300" (5/16"). If green lumber were used the estimated shrinkage would be about 0.600" (5/8"). (***Understanding Wood*** A craftsman's guide to wood technology, R, Bruce Hoadley, The Taunton Press 1980)



2—Wall-framing diagram of platform construction for a two-story dwelling shows 37.75 in. of framing members stacked vertically. From this figure the potential vertical shrinkage of the house can be calculated.

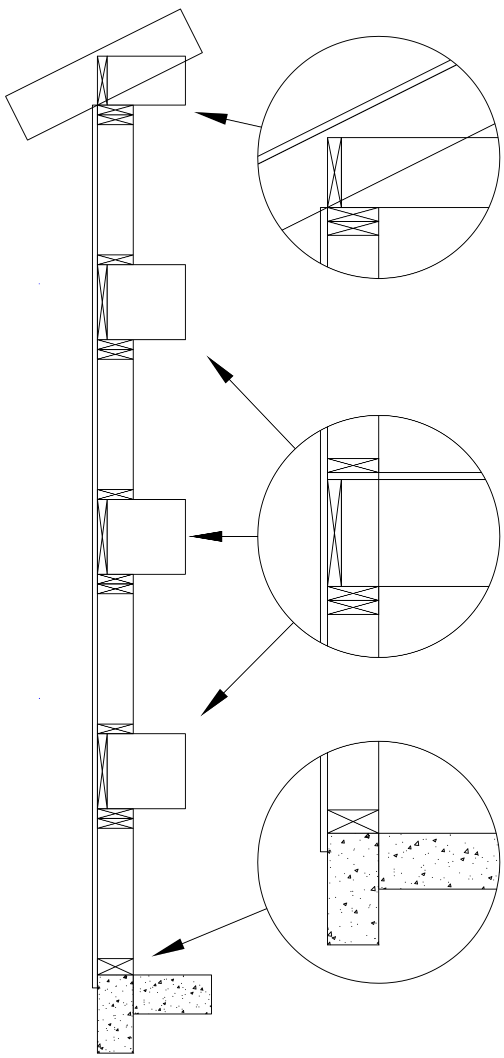


Figure 3. Shrinkage area in Multistory Wood Frame

Wood Shrinkage Information

Another widely used resource is **WWPA Technical Notes Report No 10**. Using KD (Kiln Dried) material, a shrinkage coefficient of 0.0020 (in/in/% MC change) and a stack height of 13.75" gives shrinkage across a floor of 0.248" (MC change is from 19% to 9%). If hold-downs or straps were used to connect across the floor system how is the shrinkage accounted for in the shear wall drift equation? It isn't!

Note: the shrinkage is based on KD material with a starting MC of 19%. If green joist material were used the floor shrinkage will be 0.500" (1/2"). **Shrinkage (Calculations for Multistory Wood Frame Construction**, Tech. Notes No 10, Western Wood Products Association).

Worst Case Shrinkage?

The shrinkage calculations shown above are for average conditions, average grain orientation and average material (species and moisture). But sometimes things are not average. For marketability wood is combined in wood species groups. We may not know the actual species, and shrinkage can vary by species. The wood is sometimes delivered wet and sometimes the grain is orientated tangentially. The following graphic shows the effect of grain orientation on a 2X mudsill.

Radial Shrinkage

1/16”

Tangential Shrinkage

1/8” + Typical

What happens with worst case conditions? The shrinkage calculations shown above for a 2X mudsill are for average conditions; average grain orientation, average wood species, average (low) moisture content. Just for a moment consider that mudsills for multi-story buildings are often 3X and sometimes 4X material. Also consider that pressure treated mudsills are often delivered and placed wet. Finally, some wood will be used with the grain oriented tangentially. With wet 3X mudsills some of the connections will result in shrinkage of ¼". That ¼" shrinkage should be included in the calculations.

The Tale of a Semi-Scientific Experiment.

In September of 1999 I built a marketing display with 2 X 12 lumber. The wood was Douglas fir. The height of the board measured 11.591" (9/28/1999).

Six years later the wood measured 11.079" (7/19/2005.) The wood lost about ½" in about 6 years. This year it measured 10.949" (1/15/2012). The wood lost another 1/8" since 2005. The wood was always stored indoors in a dry environment. The moisture content was never checked.

To summarize what we (don't?) know about wood shrinkage:

- We often don't know the exact wood species.
- We seldom know the moisture content.
- During construction buildings are often wet for several months.
- We can't know the grain orientation of a specific connection.
- It will take years for the building to come to equilibrium.

Design Shrinkage Recommendations. With the above in mind consider using the following:

- 0.25" per floor with engineered wood I-Joist and solid sawn lumber wall framing when products are installed and kept relatively dry (at or below 19% moisture content) during construction.
- 0.375 to 0.5" per floor with engineered wood I-Joist and solid sawn lumber wall framing when products are installed and /or allowed to get relatively wet (above 19% mc) during construction.
- 0.5" to 1.0" per floor with solid sawn joists depending on the moisture content of the lumber.