Tie-Down System Reliability

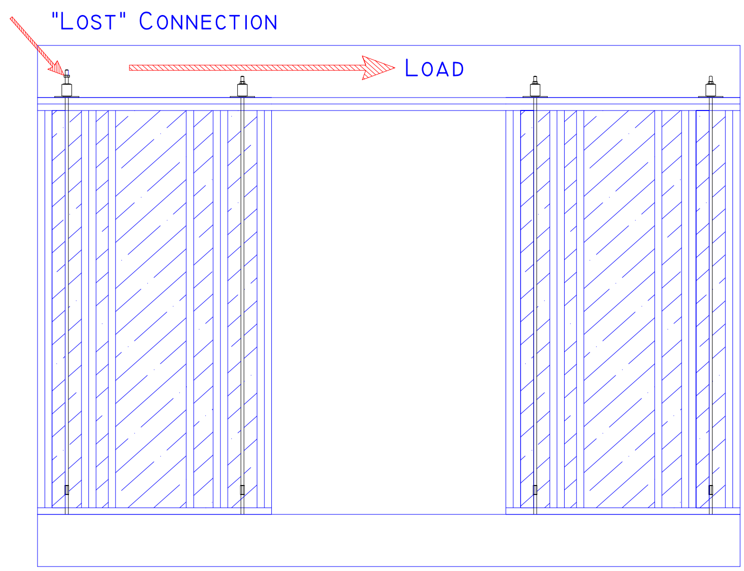
By Alfred D. Commins

Tie-Down systems resist uplift forces for wind and shear walls. Unless the tie-down system is properly designed and installed, full building performance will not be achieved. The previous paper covered system strength and elongation. This paper continues with system reliability. A complete review of tie-down systems will show some systems are robust while others are sensitive to out-of-plane and out-of-line installations. Items in part I are essentially covered in the new code AC 391 but the items contained here have not yet been fully implemented. So you aren't left with non performing systems the following is offered.

<u>Part II Tie-Down System Reliability</u>

After strength, stretch and shrinkage, system reliability must be considered. Buildings tie-down systems are moving parts. Unless the moving parts are reliable; that is, move when required, and stop when resisting uplift, the systems won't perform as expected. Reliability requires the system supplier to understand the requirements, the building designer to apply the requirements properly and the installer to properly interpret the drawing and install the parts. If any element is missing the system may not perform its intended function. This segment explores system reliability and observed deficiencies.

A brief comment about "Performance". When we say a system "won't perform" we mean that unless the connections have the same strength, elongation and tightness as the original tested <u>systems</u>, the shear walls won't deliver the full expected value per the code. Some value will remain but the performance can suffer. (See part I Side bar: "Why focus on System Elongation").



System Reliability/Deflection Compatability

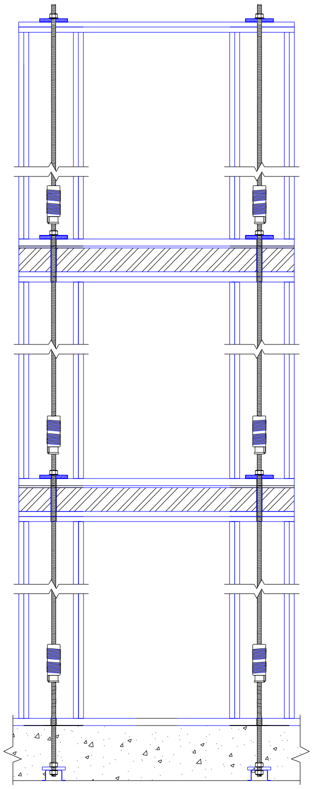
Vertical connections use self-adjusting components designed to contract or expand as the building shrinks and settles. If the connection is loose shearwall performance will be compromised. The first illustration looks at the consequences of a single tie-down not working. In this case one in four is not working.

If one in four connections is not working the shear wall can only work in one direction. Effectively we have lost <u>half</u> of our shear walls in an earthquake and maybe half our shear walls with a high wind, depending on wind direction.

The lack of deflection compatibility will tend to overstress tight walls. If one connection is loose, one shear wall is loose. A lateral load will first load the tight wall, perhaps overload that wall then shift to the loose wall. Deflection compatibility problems in the example are not good but it gets worse.

Tie-Downs: Parallel Vs Series

Two types of systems are possible depending on the location of shrinkage compensating devices. These systems are parallel or series. Parallel systems use individual shrinkage compensators at each reaction point. If one shrinkage compensator doesn't fully function that connection only affects that individual connection. A series system uses the shrinkage compensator in line and connecting vertically adjacent rods. Each shrinkage compensator carries the entire tension load of all floors above AND its shrinkage compensation affects all floors above.



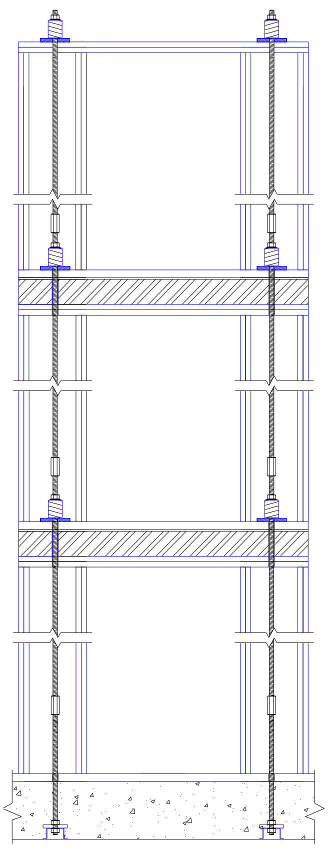
Series Loading

The system at the left is a tie-down system with all loads and shrinkage compensation in series. It may perform well if the shrinkage compensators are working but two problems may present themselves.

Each CTUD is in series. It carries the load for <u>all</u> floors above and any looseness affects all floors above. Should this moving part fail all floors above will have non-performing shear walls. In the case shown should the lowest of three shrinkage compensators fail all three shear wall will likewise fail.

With a 5 story building a single CTUD failure could destroy the effectiveness of 10 tie-down connections; the failed tie-down, the four tie-downs located above and the 5 tie-downs at the other end of the shear wall.

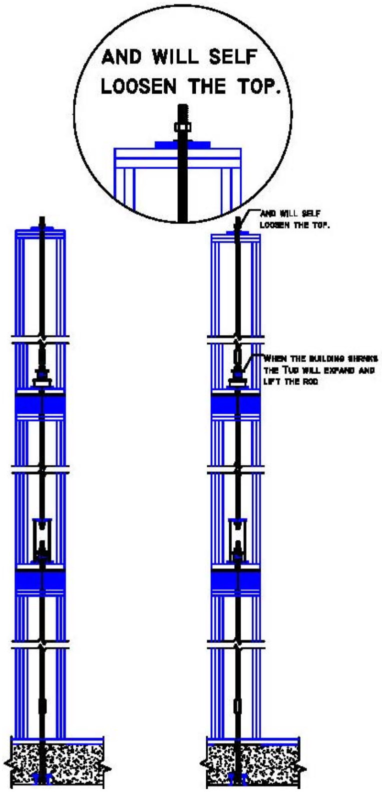
This analysis assumes that all Take-up devices may have the same reliability. Please continue reading and thinking about reliability.



Parallel Loading

The system to the left loads all reaction points in parallel. Each shrinkage compensator works individually for both loading and expansion. If one take-up device fails to expand its failure does not affect any other reaction. While the attached wall performance may be reduced the other walls will still perform. Parallel loading ensures multi-point reliability.

Designing systems for strength, elongation and shrinkage is relatively straight forward if the designer understands moving parts and shrinking buildings. Even though the parts move slowly and move over short distances, the movement or lack of movement (stuck parts) may adversely affect system performance. The design and installation of tie-down systems for reliability requires understanding the many ways a system can be installed or miss-installed. The following examples provide some guidance to the many ways systems are



mutilated. The purpose of this segment is not to embarrass suppliers or designers but to show common errors. I see most of these errors several times a month.

The Self Loosening System

The following system is an example of an improbable system. A shrinkage compensator is located on the bottom plate of the top floor. A rod extends from the floor below to the top plate above. The problem: as one floor shrinks the rod expands through the top plate above and self loosens the top floor.

To verify the logic a model was built using specified components arranged per the manufacturers' catalog. The photos below detail the installation. A toggle bolt moved the threaded rod and simulated shrinkage.

The system was installed and the shrinkage compensator was activated. As the toggle moved, the Tud expanded as expected and kept the mudsill tight to the floor. But the rod installed above the Tud expanded up through the top plate above. The loosening of the top plate was in direct proportion to "floor" shrinkage.

In essence this is a "Skipped Floor System". Systems can be designed with floor skipping in mind but every reaction point must be connected through a shrinkage compensator. In this case not only was the reaction point not connected, the system translates the movement to the top and self loosens. The model to the right details the working mock-up for the self-loosening system.

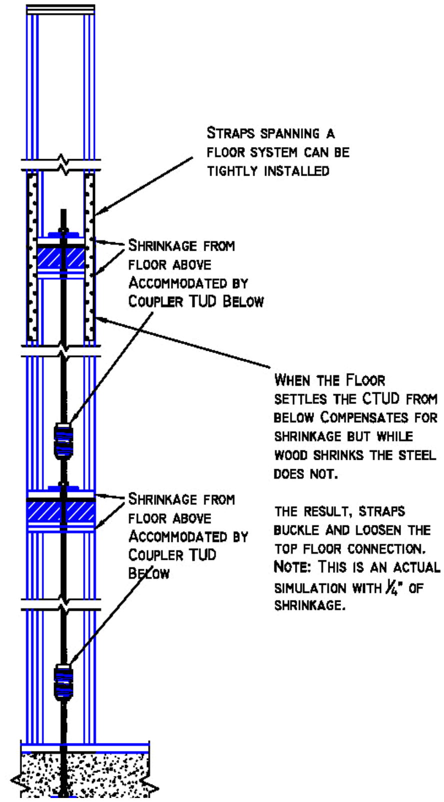
These are good materials, installed per supplier recommendations. The problem is there are moving parts that have to be accommodated. The photo to the left is an actual installation.

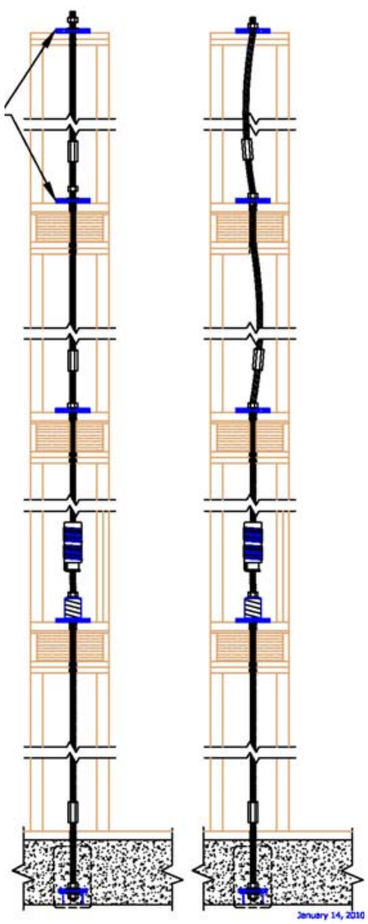
Mixing Incompatible Systems Straps and tie-down systems are often combined. The system to the left uses a shrinkage compensated tie-down system in combination with straps. At first glance this may look good but there are serious flaws.

The first photo shows the freshly installed system, ready to shrink, settle and carry load.

As the second photo shows, when the building shrinks the shrinkage compensator performs its intended function and tightens the rod. However, as the shrinkage compensator expands, the straps compress and the upper floor loosens

The floor below is tight but the floor the straps attach to is loosened. Combining a self tightening system and straps doesn't make sense. Strap buckling can be minimized if they are applied late in the construction process, but it will still be there. You can hide the buckling if the center area is nailed to the rim joist; but the buckling is still there.





Orphan Connections

Shrinkage compensating devices tend to be expensive compared to rod and plates. And sometimes the top floor is not connected with a shrinkage compensator. With only two top plates shrinkage should not exceed 1/16" to 1/8" per 2x member. If a shrinkage compensator ties the two floors shrinkage will be accommodated. Under some circumstances this might work but the premise needs to be explored.

The drawing at the right shows two floors connected with a single take-up and three reaction point plates. When shrinkage occurs one of two things can happen: either the rod will push up and loosen the connection or the rod will buckle and create a loose connection. We have seen both types of installation.

Note: in most cases only two reaction points are connected through a CTud. What is shown is an extreme case.

Jammed Connections

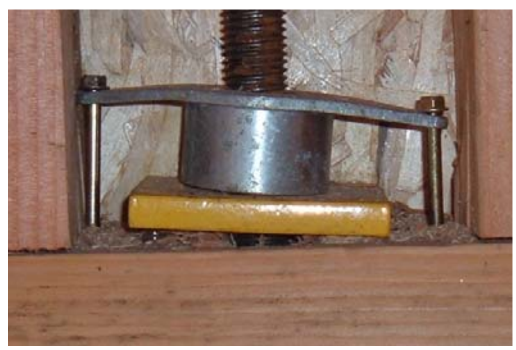
Shrinkage compensating must be installed per the manufacturer's recommendation, the ICC ES Code report and common sense. Jammed connections that lock the shrinkage compensator in place may lock the connection and fix the rod in place.

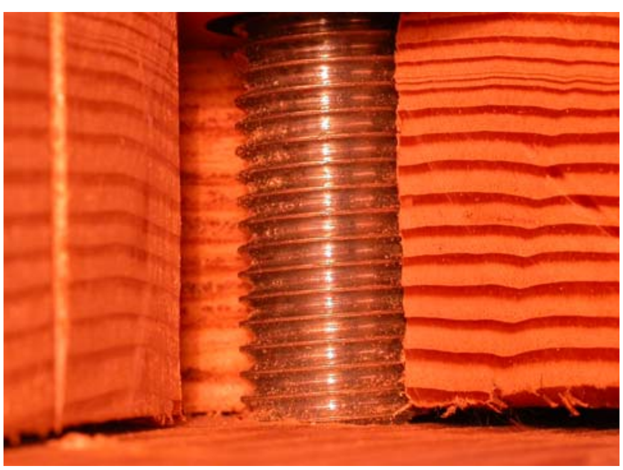
Jammed connections can be caused by: undersize holes, misaligned holes, pinched connectors, and out-of-square or out-of-plumb rod, out-of-square shrinkage compensators and insufficient headroom. With a jammed connection often the rod will buckle. Buckling is most common on the upper stories with lighter rod. Eight to ten feet of small diameter rod can easily buckle under the right conditions. If hidden behind sheet rock it may never be noticed.

a. **Undersize holes**. Typical bolt holes in wood are drilled 1/16" oversize. Vertical rod systems are different. In most cases the rod is not fixed in the hole; rather it is designed to slide up through the holed. Therefore we recommend vertical holes used in tie-down systems be drilled ¼" to ½" oversize. In the photo a cage was used to join rod. The shrinkage compensator above didn't have the strength to lift the rod through an undersize and/or out-of-plumb clearance hole. The result is a loose connection. Since this is a series system the <u>entire run above</u> has failed.

b. **Misaligned Holes**. Holes should be drilled vertically and in-line with the holes above and below. This allows rod to slide through the hole as the building settles. A misaligned hole that is out-of-square and/or out-of-plumb can bind and buckle the rod. See illustration

c. **Out-of-square connector.** Some shrinkage compensators are fixed to the plate with screws. Sometimes the screws connecting the take-up are tightened on one side more than the other, resulting in a cocked connection. This out-of-square connection binds the rod and take-up. As the building shrinks, the take-up bends, or the rod buckles. (See the illustration on the top of page 14). Controlling a 2 degree out-of-square connection can be difficult.





d. **Pinched Rod** Some Tuds (shrinkage compensators) attach to the top plate with screws. The screws secure the Tud allowing the moving rod to ratchet. Occasionally builders and inspectors have noticed rod buckling especially on upper floors with small diameter rod. Sometimes this was due to an out-of-square Tud installation in other cases rod buckling has been blamed on under size holes. But there appears to be another more likely cause, rod-wood friction.

In the photo the ¾" diameter rod is installed in a 1-1/4" hole, but the rod is still fixed in hole. (Note the clearance to the left of the rod.)

The shrinkage compensator is screwed to the plates. During installation the installer tends to push the rod to the back of the bay. (His natural inclination as he installs the screws.) Screws also tend to be installed at an angle. This can "lock" the rod to the wood plate. As the building shrinks the locked rod buckles. Buckled rods means the building is not attached. (See buckled rod under Orphan Connections)

e. **Insufficient headroom.**

Rod systems need to expand as the building shrinks. The rod to the right doesn't have sufficient room to expand. The solution is to relocate the Shrinkage Compensator to the floor above.

f. Insufficient Side Clearance

Some shrinkage compensators have external springs. As the devices expand vertically the springs expand horizontally. If the spring hits the side of the tie-down or enclosure the vertical expansion can be stopped.

Solution: Ask the supplier how much the device will expand (diameter) as it grows in height. And make sure the product has outside clearance to accommodate the expanded spring.

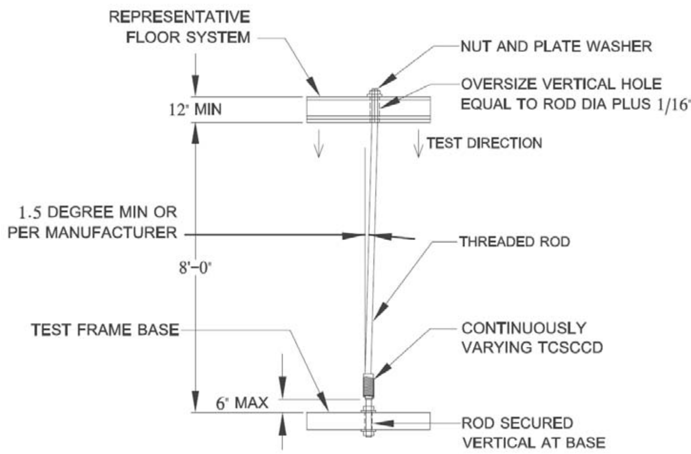
g. Jammed Shrinkage compensator

The shrinkage compensator shown at the right is stuck in a retracted position. Several factors may "freeze" the device.

This device uses a ratchet with a small diameter bearing surface (a wire ring). Under loading the wire may ding the surface and lock the device. Loading associated with a wrenching of the device in place may be sufficient to jam the device.

h. Interfering Rod. When cages are used rod cut length can be critical. If the rod is cut too long, the shrinkage compensator may expand and the rod ends can hit. Further expansion is impossible.

j. Out-Of Plumb. Most shrinkage compensating devices have been tested at an inclined angle of 2 degrees or more. Some devices are more sensitive to out-of-plumb installation and are restricted to a test angle of 1.5 degrees, and an installation angle of 1 degree.



The 1 degree out-of-plumb may contain a “gotcha”. While the standard calls out a 1 degree angle that angle assumes “un-sprung” rods. Let me explain. Rods can penetrate a foundation or floor at a considerable angle. Alignment will only occur if the rod is sprung into place. But a performance penalty may result. Residual stresses left in the rod may try to straighten the assembly. If the shrinkage compensator is a Coupler Take-Up the threaded device must turn in order to adjust. Rotating devices may not turn when a “kink” or out-of-square connection is made. Suggestion, observe CTud installations to insure the rods are not “sprung” into a tortured alignment.

Most system suppliers suggest an out-of-plumb limit of 1-3/4” to 2” in a 10’ floor system. A one degree out-of-plumb connection is just over 2” in 10’. Some systems may stop expanding with a 1 degree out-of-plumb condition. Systems with “floating” shrinkage compensators may accommodate 4” (in 10’) or more of out-of-plumb. Ask your supplier.

Summary

Systems with moving parts are difficult to design and install. Some systems and parts are very difficult to install properly. Should there be non-functioning (stuck) system the scapegoat has always been and will be the contractor.

As you design a building tie-down system, please consider all key performance functions associated with connections including strength, stretch (elongation), shrinkage and reliability. Of these I consider reliability the most difficult to master and most likely to trip up the engineer, supplier, and installer.

Best Regards

Alfred Commins

Friday Harbor, Washington 98250

Alfred Commins has been designing structural connectors for 35 years. He currently has more than 40 U.S. and Foreign patents in the connector and other industries. He is the President of Commins Manufacturing Inc. Prior to that, he managed Research and Development for Simpson Strong Tie Inc.

Please call or e-mail with comments, questions or suggestions.

al@comminsmfg.com 360-378-9484