Continuous Tie-Down Systems...

For Wood Panel Shear Walls in Multi Story Structures

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Introduction

With the recent increase in construction of multi story wood framed structures has come a demand from builders and engineers for an alternative from the "traditional" shear wall hold-down systems. The loads generated in such structures are commonly in the range of 30 to 40 kips on the ground floor. To accommodate such loads using "traditional" systems has at times proven to be time consuming and expensive to install. Continuous tie-down systems are relatively new, simple, and economical solutions.

The design and detailing procedures for these hold-down systems are not the same as the "traditional" hold-down systems. This article presents a brief generic review of designing, detailing and specifying of these systems. A more in-depth review is available on line at **www.structuremag.org**.

Examples of existing "traditional" tie-downs (hold-downs) on the market today are metal straps, bent/folded steel devices or structural steel sections in combination with steel anchor rods. Most of these hold-down systems are proprietary and have ICBO ES approvals.

Generic representations of continuous tie-down systems are shown in Figures 1A & 1B.

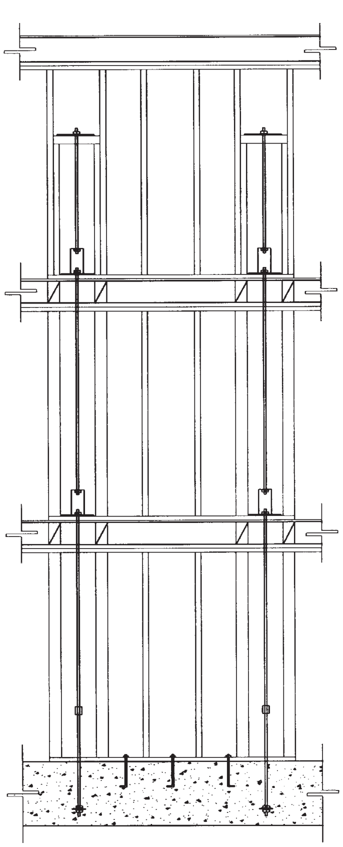

Figure 1A: *Illustration of a continuous concentric tie-down system using bearing plates.*

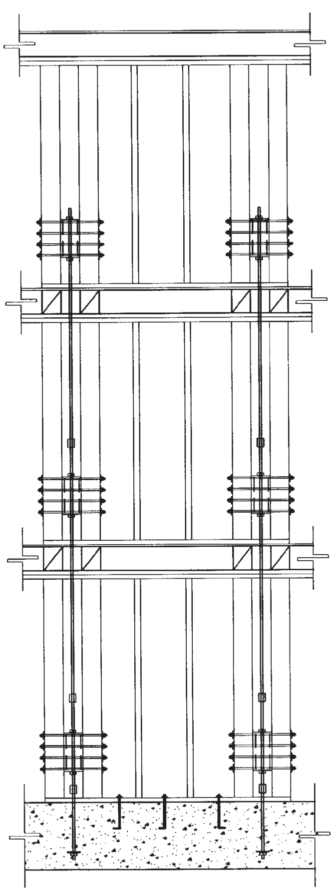

Figure 1B: *Illustration of a continuous concentric tie-down system using bolted hold-down devices*

Design Issues

Design of wood shear walls has traditionally been limited to utilizing code approved allowable stresses coupled with limits on the aspect ratio of the shear walls. The tension and compression capacity of the end-posts, shear wall deflection, shrinkage, and eccentric loading have sometimes been ignored. However, code compliant structural calculations should be used to check all of the components of the shear wall.

Recommended Shear Wall Design Steps

1) Determine lateral load using code approved base shear formulas.
2) Distribute load vertically to stories in the structure.
3) Distribute lateral loads at each level to the resisting elements using a rational method, which considers the rigidity of the diaphragms and resisting elements (flexible diaphragm assumption should not be made without verification of diaphragm deflection relative to shear wall deflection).
4) Design/select wood sheathing and fasteners.
5) Design/select base horizontal anchorage.
6) Design/select ***overturning anchorage***.
7) Check wood framing members for moisture content. Include shrinkage in shear wall displacement calculations.
8) Check shear wall displacement against code allowable.

Deflection of a Wood Shear Wall

UBC§2315.1 & IBC §2305.3.1 provide deflection limits for wood shear walls… "*deflection in the plane of the shear wall….does not exceed….the permissible deflection*". The permissible deflections are found in *UBC §1630 & IBC §1617*.

The basic equation (*UBC§23.223, Vol. 3 & IBC §2305.3.2*) to determine the deflection of a wood shear wall is shown below:

$$\Delta = \frac{8vh^3}{EAb} + \frac{vh}{Gt} + 0.75he_n + \frac{h}{b}d_a$$

The first term in the shear wall deflection equation represents flexural contribution to the overall deflection. The second term represents shear deflection and the third term represents nail deformation between the sheathing and framing. Finally, the fourth term represents the contribution of the ***tie-down assembly displacement***.

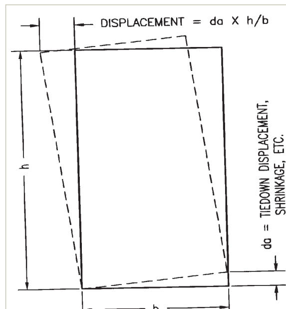

Figure 2: *Shear wall deflection from tie-down displacement*

Continuous Tie-down Assembly Displacement

Tie-down assembly displacement (d_a) is a combination of elements contributing to the overall deflection of the shear wall:

1. **Tie-Down Rod Elongation**. Rod elongations should be checked for the length of rod between load transfer devices. Some jurisdictions have placed 1/8 inch per floor limits on components of the tie-down system. It is essential to check rod elongations when skipping floors.

2. **Tie-down Transfer Device Deflection**. The tie-down transfer device deflection varies depending on the type of device and magnitude of the load. Some of the tie-down manufactures supply this information in their catalogs.
3. **Oversized Bolt Holes**. Oversized bolt holes are primarily due to the quality of construction. The contribution to anchorage device displacement from oversized bolt holes, as required by Code, ranges from 1/32 (0.0313) inch to 1/16 inch, yet can be as much as 1/8 (0.125) inch when the bolt holes are poorly installed.
4. **Sill/Top Plate Crushing**. The allowable compression stress design values ($F_{c\perp}$) perpendicular to grain are based on a deformation limit associated with a deformation level of 0.04 inches. For a reduced deformation limit of 0.02 inches use of $F_{c\perp 0.02} = 0.73\ F_{c\perp}$. This corresponding deformation must be added to the vertical deflection of the anchorage system.
5. **Wood Member Shrinkage**. *UBC§2304.7 & IBC§2303.7* Shrinkage consideration shall be given in design to the possible effect of cross-grain dimensional changes considered vertically which may occur in lumber fabricated in a green condition. Instances have been recorded where shrinkage has exceeded 0.50 inches per floor.
6. **Short posts and lack of square ends.**

The majority of the proprietary tie-down systems compensate for shrinkage by pre-tensioning of the rod or by self-ratcheting devices, or by expandable elements within the system. These shrinkage-compensating devices are highly recommended in tie-down systems for multi-level wood frame construction. Shrinkage, if not compensated for in the tie-down system, will add to the fourth term of deflection in the shear wall deflection equation and allow the shear wall system to go through considerable deflections before tie-downs are even activated. In addition, the shrinkage compensating devices will normally compensate for other slack in the tie-down system caused by crushing of plates and joists, seating of end-posts, studs, etc.

Boundary Element Check for Compression Parallel to Grain

Compression parallel to grain on the end-posts can often be the controlling design capacity. Shear wall sheathing must be adequately nailed to compression members to transfer the story compression forces. Additional members required due to accumulation of compressive loads from above need only be nailed to the structural sheathing for weak axis bracing.

Detailing

There are three basic types of continuous tie-rod systems currently in-use:

1. **Bearing type of system** consists of a continuous threaded rod coupled with a steel plate that is installed either at the sill plate above the shear wall being held down, or to a bridge block at or near the mid-height of studs on the shear wall being held down. Figure 1A shows the typical configuration for a bearing type of system.

   Key points are: (1) when using the bridge block method of terminating the rod and plate washer, the studs below the bridge block at the termination point must be adequately connected to the full height end-posts in the shear wall, and (2) the use of a bearing plate requires that the manufacturer select a plate that satisfies bearing perpendicular to the grain of wood, bending in the steel plate, and shear in the steel plate. If the resulting bearing plate length exceeds the manufacturer's standard clear distance between end posts then this distance may be increased by the manufacturer which results in a different position for the continuous rod and an increased moment arm (distance between tension rod and compression end posts) for overturning calculations. The plate should not be installed underneath the end-posts.
2. **Bolted type of system** consists of a continuous threaded rod coupled with fabricated steel connectors, which are bolted to end-posts in the shear wall being held down. Bolted systems should consider the capacity of the bolts in the end-posts, the tension capacity at the net section of the end-posts, the capacity of the steel connector, and the capacity the rod. Figure 1B shows the typical configuration bolted type of system.

   Key points are: (1) ensuring the correct end distance from post ends to bolts, and (2) using the net section of the end-post to calculate allowable tension capacity (3) ensuring bolt holes are not over drilled.
3. **Hybrid type of system** combines 1 or 2 with floor-to-floor straps at the upper levels. When straps are installed over the structural sheathing, boundary nailing in the sheathing should be omitted to reduce perforations in the sheathing. The use of continuous tie-rods is eliminated at a level where the loads are smaller. The load path is slightly different since the tension loads at the upper levels accumulate onto end-posts rather than a tie-rod. Unlike the completely continuous tie-rod system, in a hybrid system, the bearing plate or shear connector device installed at the highest elevation must be capable of resisting the tension load on the level of installation plus accumulated tension loads above that level.

A single end-post at the strapped level can be strapped to one of the double end-posts of the continuous tie-down system. Both end-posts of continuous tie systems must have boundary nailing. The boundary nails of the single continuous tie down system end-post receiving the strap must have the capacity to resist the uplift force at that level plus the force from the strap. This will assure an equal distribution to both end-posts.

Since shrinkage compensating devices cannot be installed at strapped levels, shrinkage effects must be considered and included in shear wall deflection equations. It is advisable to attach straps as late as possible in the construction sequence to allow a good portion of the shrinkage and building settlement to occur first.

Drawings

Tie-down system specification on structural drawings may be done in one of the two following recommended formats.

(1) Specify a particular manufacturer and the specific components for the tie-rod system, using standard catalog callouts or available engineering software and/or drawings from the manufacturer or (2) specify the accumulated uplift force at each level on the design documents and the necessary performance criteria for the installed tie-down system.

Minimum parameters necessary to specify the performance criteria for the tie-down system are: (1) the individual uplift loads at each level, (2) displacement limits for elements of the tie-down system at the specified uplift loads, (3) whether or not connections at floors can be skipped, (4) whether or not shrinkage compensating devices are required.

Minimum end-post sizes must also be specified since the end-post size is typically determined by the compressive demand. If levels are allowed to be skipped, the compressive load on end-posts will accumulate to the level, which is restrained. The tension loads on connectors (bearing plates or bolts) will accumulate to the highest connected level. Header or beam loads must also be considered.

It is recommended that tie-down shop drawings be prepared much the same as for pre-manufactured systems. If the tie-down shop drawings mandate engineering work they must be stamped and signed by a licensed Civil or Structural Engineer. Additionally, these shop drawings must be reviewed and approved by the general contractor, engineer of record, and the governing building department prior to fabrication or installation.

While the construction industry gains experience in the installation of these hold down systems, it is desirable to have the engineer of record observe at least a sampling of the installations to ensure proper use.

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Summary

Continuous tie-down systems provide an economical and structurally sound method of resisting overturning in multiple story wood framed buildings.

- To design/specify a continuous tie-down system the design engineer must:
- Distribute lateral load to resisting elements using a rational method which considers the rigidity of the diaphragms and resisting elements.
- Determine individual/accumulated uplift forces at each level
- Specify the tie-down system
  1) Select a particular manufactured system and its components or
  2) Provide accumulated uplift loads at each level
- Determine or specify tie-down system contribution to shear wall deflection due to
- Determine deformation due to sill and top plate crushing from compression perpendicular to grain
- Determine shrinkage
- Specify if shrinkage devices are required
- Specify if transfer/restraint device may skip levels
- Specify end-posts:
  1) For tension on net section
  2) For compression parallel to grain (include header, beam, etc. loads)
  3) For crushing of sill plates for compression perpendicular to grain

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