



# Seismology and Structural Standards Committee

Seismology Publication

May 2008

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## Hold-Down Devices and ICC AC155

### Scope:

This article provides discussion of typical light-frame shear wall hold-down hardware and associated Acceptance Criteria developed by the International Code Council Evaluation Services. The potential for

damage and excessive drift resulting from hold-down deformation is explored. Recommendations for how engineers should deal with these issues with respect to hold-down design are provided herein.

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### Symbols and Abbreviations:

See *Publication for Symbols and Abbreviations (in context)*

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### References (footnoted in text):

1. Acceptance Criteria for Hold-Downs (Tie-Downs) Attached to Wood Members, AC155 (approved 10/05, effective 3/06) (see [http://www.icc-es.org/criteria/pdf\\_files/ac155.pdf](http://www.icc-es.org/criteria/pdf_files/ac155.pdf)), by the International Code Council Evaluation Service, Inc. (ICC-ES)
2. American Society of Civil Engineers / Structural Engineering Institute (ASCE/SEI) Minimum Design Loads for Buildings and Other Structures, Standard 7-02
3. American Society of Civil Engineers / Structural Engineering Institute (ASCE/SEI) Minimum Design Loads for Buildings and Other Structures, Standard 7-05
4. Numerical studies of the shear wall deflection equation by SEAOSD Seismology committee members
5. Test data from Report No. T2004-14 by the American Plywood Association (APA)
6. Comparisons of March, 2002 Consortium of Universities for Research in Earthquake Engineering (CUREE) 1.4.4 testing and December, 2001 City of Los Angeles – University of California, Irvine (CoLA-UCI) testing
7. ATC R-1 Cyclic Testing of Narrow Plywood Shear Walls, 1995 by the Applied Technology Council
8. 'Seismic Testing of a Full-Scale Woodframe Building' pp. 239-249 of the *2007 SEAOC Convention Proceedings*
9. 2003 National Earthquake Hazards Reduction Program (NEHRP) Commentary for Section 12.2.3.11 and 12.2.3.12
10. 'Hold-Down Connectors and Wood Member End-Post Capacity' by Rawn Nelson in *Structure*, September 2001
11. ATC R-1, section 3.2.1
12. National Design Specification, NDS-2001 by the American Forest & Paper Association (AF&PA).
13. 'Effect of Eccentric Overturning Restraint in Complete Shear Wall Assemblies' by Steve Pryor, 2002 (see [http://www.strongtie.com/literature/TechTopics/eccentric\\_restraint.htm](http://www.strongtie.com/literature/TechTopics/eccentric_restraint.htm))

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### Authorship:

This publication represents views endorsed by the SEAOC Seismology Committee. It may differ from the views, methods, policies and interpretations of some building authorities. Engineers are cautioned to ascertain such views, methodologies, policies and interpretations in advance of design.

This document was originally authored by members of the Structural Engineers Association of San Diego.

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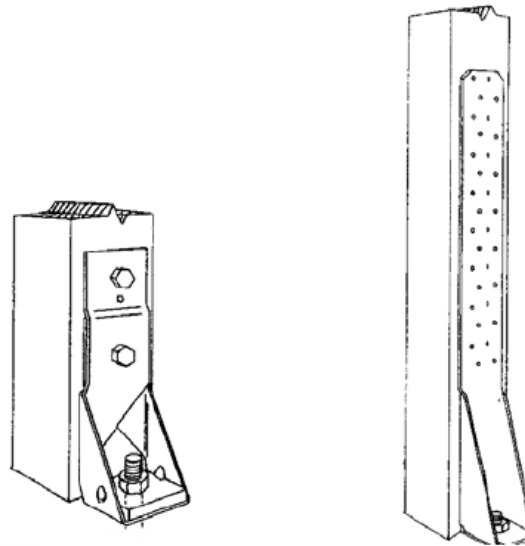
## Acknowledgement

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This article focuses on the behavior of hold downs (tie-downs) and their impact on shear wall performance.

Optimum wood shear wall performance results when the contribution to drift from the hold-down assembly is held to a minimum. The hold-down assembly is defined as the bracket, the anchor rod, the fasteners attaching the bracket to the wood post and any washers/bearing plates used to limit wood crushing. See Figure 1 from ICC's AC-155<sup>1</sup>.



**FIGURE 1—ILLUSTRATIONS OF A BOLTED HOLD-DOWN (TIE-DOWN) ASSEMBLY (LEFT FIGURE) AND A SCREWED OR NAILED HOLD-DOWN (TIE-DOWN) ASSEMBLY (RIGHT FIGURE)**

Some, if not all, of the following effects can increase the contribution of a hold-down assembly to shear wall deformation:

- Uneven building settlement causing pre-loading of the shear wall
- Excessive moisture content of wood framing causing shrinkage and vertical shortening of wood framing
- Sill plate crushing and elastic through-floor compression under compressive loads
- Slip or looseness within various shrinkage compensating devices



- Localized crushing of wood end post or stud at connection of hold-down fasteners
- Deviations from assembly design (wall length, sheathing attachment, bracket placement, post species, post over-notching/boring, etc.)

The ICC Evaluation Services Acceptance Criteria: *Acceptance Criteria for Hold-Downs (Tie-Downs) Attached to Wood Members*, AC155 (approved 10/05, effective 3/06)<sup>1</sup> references ASCE 7-02<sup>2</sup> and NDS-2001<sup>12</sup>.

AC155 section 4.4.3 indicates that the permitted displacement of the hold-down assembly is 0.25 inches when tested on a wood post or 0.185 inches when tested on a steel jig, based on strength level forces. A four-foot long shear wall subjected to the full 0.25" hold-down displacement will see 0.52% elastic story drift due to rigid body rotation or 83% of the allowable drift from the hold-down deformation alone (the 'd<sub>a</sub>' term in the shear wall deflection equation). This indicates that hold-downs complying with AC155 can provide a significant contribution to total story drift.

The elastic story drift limit for light frame buildings of Occupancy Category I or II per Table 12.12-1 of ASCE/SEI 7-05<sup>3</sup>, is typically 0.625% (2.5% inelastic). When considering Occupancy Categories III and IV, the allowable drift is met and exceeded, respectively, based on the hold-down deformation component alone. For narrow shear walls (i.e. aspect ratio of 2:1 or greater), hold-down deformation contributes roughly 50% to 60% of overall wall deflection with nail slip contributing roughly 20% to 30% of the overall wall deflection<sup>4</sup>. As walls become longer, the hold-down component of overall wall deflection diminishes in effect, while the contribution of the nail slip term increases (e.g. for aspect ratio of 0.5:1, the hold-down component decreases to roughly 20% to 30% of overall wall deflection and the nail slip component increases to roughly 40% to 50% of the overall wall deflection<sup>4</sup>). This analysis indicates that a wall with multiple components loaded to a level close to their respective strength limits will exceed the code prescribed drift limit. The numerical study performed by SEAOSD Seismology Committee<sup>4</sup> members also identified that some hold-downs, with substantial force capacity, may well exceed the hold-down deformation limit specified by AC155, (from 24% to 104% above acceptable limits).

As these components experience deformation, damage to structural and non-structural components can occur especially in narrow shear walls. However, deformation associated with hold-down components should be considered in context with wall aspect ratio and wall stiffness. Understanding the deformation of the individual elements and their impact on the behavior of the wood sheathed shear wall behavior is critical to understanding the importance of hold-down deflection behavior and limits. Load-slip curves<sup>5</sup> for nails and wood sheathing indicate that initial yielding of nails occurs at a local deformation of approximately 0.1" between the wood sheathed panel and wood support members. Tests of shear wall assemblies<sup>6</sup> indicate that yielding of the shear wall system occurs between 0.2" and 0.5" of top-of-wall lateral displacement for an 8-foot "tall" panel (e.g. maximum of 0.5% drift). The variance in the shear wall yielding (i.e. between 0.2" and 0.5") can be attributed to variable nail spacing and/or variation in wall length tested.

There are popular hold-down devices (hold-downs) that are not currently approved under ICC Evaluation Services Acceptance Criteria: *Acceptance Criteria for Hold-Downs (Tie-Downs) Attached to Wood Members*, AC155 (approved 10/05, effective 3/06)<sup>1</sup>. Many hold-downs currently hold ICC Evaluation Service Reports based upon older acceptance criteria, AC13, which was created for joist hangers and other hanging devices; hardware that is dissimilar in behavior and purpose to hold-downs. Similarly the tabulated values may not be possible to develop given the new restriction on anchor design.

Foundation sill plate splitting has been observed in tested shear wall assemblies and during post-earthquake damage inspection<sup>7,8,9,10</sup>. Sill plate splitting is often more pronounced for narrow shear walls<sup>7</sup>, typically in the presence of high capacity hold-downs. In fact, sill plate splitting was observed during static load tests of narrow plywood shear walls<sup>11</sup> at an end post vertical displacement of approximately 0.2 inches. The tested assembly was constructed with anchor bolts fastened with nuts seated on standard round washers rather than square, thicker steel plate washers currently required by the International Building Code.



Sill plate damage is commonly attributed to differential movement between the rigid attachment of the sill plate at the anchor bolts and the flexible behavior of supporting studs and wood sheathing panel. This differential movement results in cross-grain bending of the sill plate between sheathing nails and anchor bolts<sup>9</sup>. The code provisions attempt to limit such damage through dictating limits on the distance from the end of the sill plate to the nearest anchor bolt (e.g. 2001 CBC Section 1806.6, 2007 CBC Section 2304.3.4 [DSA-SS & OSHPD 1, 2, and 4] item 2) as well as limiting cross-grain bending stresses at anchor bolts through the use of thicker square steel plate washers (e.g. 2001 CBC Section 1806.6.1, item 2, 2007 CBC Section 2305.3.11). Although designing for durability is beyond the scope of this article, the designer is reminded to carefully study potential corrosion on the hold-down assembly from preservative-treated lumber.

Hold-down deformation has also been cited for contributing to the failure of nails connecting the sheathing to the sill plate<sup>9</sup>. For dynamic and static load tests of narrow walls<sup>7</sup>, slippage and/or deformation of the hold-downs was cited as the initiating event for eventual shear wall failure.

The ICC has indicated that they currently do not intend to compel hold down manufacturers to update their Evaluation Services Reports to the new AC. Discussions with a popular hold-down manufacturer indicate that they intend to submit hold-down test data consistent with AC155 to ICC Evaluation Services in early 2008. The publication of an ICC ESR for relevant products will likely not be available until late 2008.

Given the potential damage to shear wall components, increased story drift and damage to structural and nonstructural components, the SEAOC Seismology Committee recommends that engineers account for hold-down deflection in shear wall design.