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# AISI Committee on Specifications New Test Standard for Hold-downs Attach to Cold-formed Steel Structural Framing

Jeff Ellis

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# AISI Committee on Specifications' New Test Standard for Hold-downs Attached to Cold-Formed Steel Structural Framing

Jeff Ellis, P.E., S.E.[1]


## Abstract

This paper discusses the new hold-down test standard entitled "Test Standard for Hold-downs Attached to Cold-Formed Steel Structural Framing" [1] developed by the AISI Committee on Specifications for the Design of Cold-Formed Steel Structural Members. Currently, the other AISI test standards are shown in the 2002 AISI Cold-Formed Steel Design Manual [2]. Hold-downs are defined in the AISI General Provisions standard [3], which is referenced by the 2006 International Building Code [4], and have been used successfully for many years in light-frame cold-formed steel construction. The 2006 IBC Section 1604.9 requires a continuous load path to transmit forces induced to structural members and systems to the foundation. Hold-downs are commonly used as the attachment of a structural member, such as a post or joist, to the foundation or wall to complete the load path. Understanding their strength and displacement behavior is important to the proper design and detailing of cold-formed steel light-frame lateral force resisting systems. This test standard provides a standard methodology that may be used to determine and compare strength and displacement characteristics for the many types of devices used in the industry currently and that may be developed in the future.


[1] Senior Engineering Project Manager, Simpson Strong-Tie Co., Inc., Pleasanton, CA
AISI COFS Lateral Design Subcommittee Chairman

**Introduction**

Hold-downs are used to resist overturning forces in light-frame shear walls, or to resist uplift in vertical framing members, to resist lateral forces at wall to diaphragm connections, or to transfer lateral forces between framing members in horizontal diaphragms. These forces are typically induced by wind or seismic events. Usually, hold-downs resist tension forces, but there are some that may also be used to resist compression forces. The 2006 IBC references the 2004 AISI Lateral Design standard [5] in Section 2210.5. It is a requirement in both the 2004 [5] and 2007 [6] Lateral Design standard Section C2 that hold-downs be used in Type I and Type II cold-formed steel framed shear walls as the prescriptive shear wall values tabulated in the Lateral Design standard [5] [6] were based upon tests using hold-downs.

The building code specifies certain strength requirements for hold-downs in shear walls when the Response Modification Coefficient, R, is greater than 3 [6] and it specifies strength level (LRFD) story drift limitations - for seismic load resistance - for which the hold-down in a shear wall contributes towards [7] as shown in Figure 1. There are also specific strength and detailing requirements for hold-downs used to resist seismic forces in framing members of horizontal diaphragms [7]. These code requirements are reasons that deformation behavior is important in addition to strength determination.

Given the impact that hold-down performance has on the response of the lateral force resisting system, and thus the entire building, it was determined that a stand-alone hold-down testing standard was needed. Hold-downs have been evaluated in the past typically using Chapter F, Tests for Special Cases, from the AISI specification of which the most recent is the AISI 2007 North American Specification for the Design of Cold-Formed Steel Structural Members [8]. This has meant that a minimum of 3 tests, with no more than a 15% deviation from the average value of all the tests, were performed and then a resistance factor was determined per this chapter to determine the hold-down design strength. In some cases, hold-down device displacements were also provided.

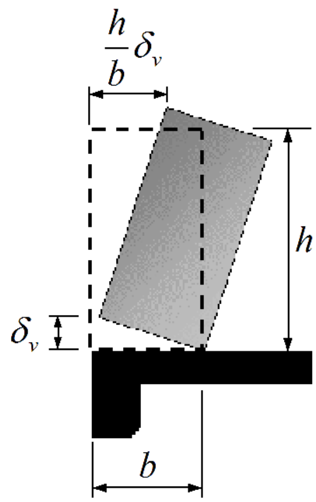


Figure 1 – S213-07 Figure C2-10 – Lateral Contribution from Anchorage/Hold-down Deformation

**Scope of Standard**

The standard provides a methodology to determine both the strength as well as the deformation characteristics of the hold-down device itself (device test) as well as the overall assembly with the hold-down attached to a light-frame member(s) (assembly test). There are several hold-down types that may be evaluated using this standard as shown in Figure 2, but other types of similar hold-downs may be evaluated under this standard, as applicable.

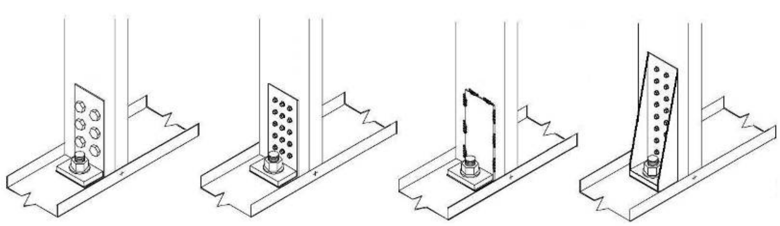

Figure 2 - Typical Hold-down Assemblies

## Test Fixture and Specimen

The test fixture may be either a hydraulic or screw operated testing machine that must be able to provide a constant rate of loading along with a calibrated device to measure the load. Alternatively, a hydraulic cylinder with a steel fixture and a load cell may be used.

The specimen is the hold-down device itself or the hold-down and the fasteners specified to attach it to the cold-formed steel framing member(s) when the assembly test is performed. The minimum number of test specimens and the permissible test result variation is per Chapter F [8] which requires a minimum of 3 tests and each individual test must be within 15% of the average or until at least a total of 6 tests are performed.

As is typical for any structural member test, it is required to determine the material properties of the hold-down device inclusive of yield and tensile strength and the base metal thickness. The material strength and thickness of the cold-formed steel member(s) that the hold-down is attached to in the assembly test also affect the test results and need to be determined. The fasteners used in the test are required to be sampled at random and installed as they would be in the field or if welds or other fastenings (i.e.; clinching, etc.) are used, their installation is to be the same as that performed in the field.

## Test Setup

It is required that the hold-down be tested individually and that the test setup represent the position and loading of the hold-down in the field. As many of these hold-down devices are eccentric, it is permitted to use low-friction material to support the steel jig or cold-formed steel members below and above the hold-down.

The anchor bolt is required to be installed to simulate field conditions as best as possible. This would include that the anchor bolt should not be longer than typically expected in the field, the anchor bolt nut should have the same bearing area as the one used in the field, and the anchor bolt nut should only be snug tightened if it is possible the hold-down might be supported by something other than a rigid structural steel or concrete or masonry base (ie; raised hold-down installation, wood sill plate, etc.). In addition, the fasteners used to attach the hold-down to the cold-formed steel members should be installed to also represent possible field conditions. For example, this would mean that the nuts for the bolts should only be snug tight unless the installation instructions state specific tightening requirements.

## Hold-down Device Test

The hold-down device test requires the hold-down device be attached to a steel fixture, as shown in Figure 3, and this is to determine the strength of the device itself. The deformation is

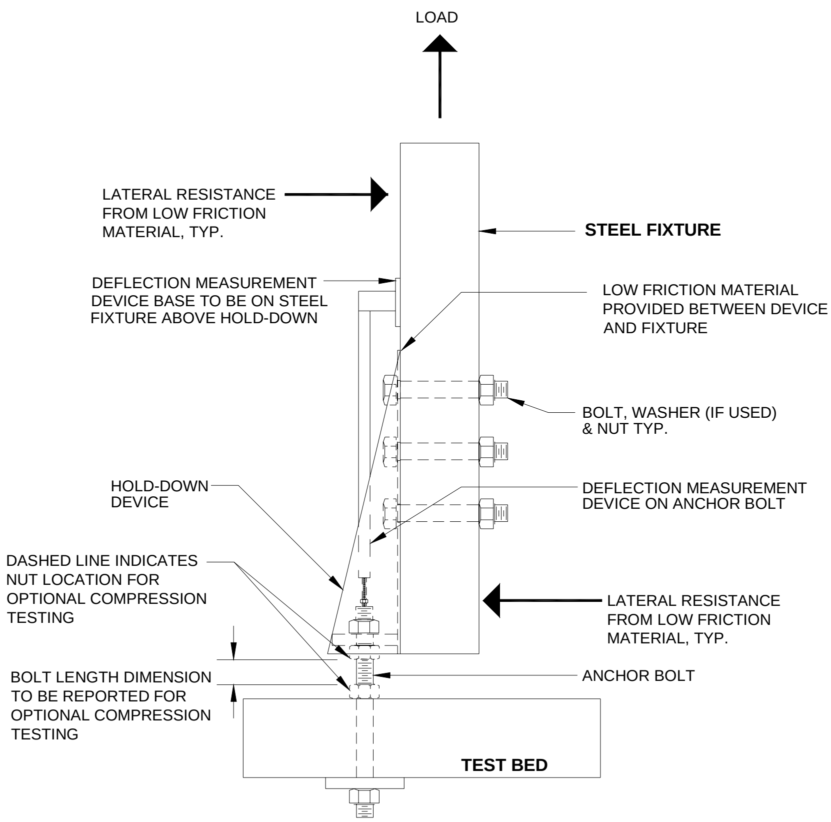


Figure 3 - Tension Load Test Set-up for a Single Hold-down Device

inclusive of the hold-down deformation, fastener slip, and anchor bolt elongation. For tension load testing, the hold-down is required to be installed a minimum of 1” above the test bed to account for raised hold-down field installations or when the hold-down may be installed on top of a non-rigid (i.e.; wood) base. It may be required to test the hold-down raised higher than 1” if the hold-down may contact the test bed, such as through seat rotation, prior to failure. It is also required that a low friction material be placed between the hold-down and the steel test jig to minimize friction or bearing resistance from the steel fixture.

If the hold-down is required to be installed in the field to a rigid structural steel or concrete base, it is permitted to test the hold-down with it installed directly on top of the test bed, similar to the test setup shown in Figure 4b. When a hold-down is tested directly on the test bed, the anchor bolt should be instrumented so that the force to the anchor bolt can be measured and compared to the applied force as some hold-downs may amplify the applied force to the anchor bolt due to prying. This anchor bolt force information is needed by the designer so that the anchorage may be properly designed and detailed.

The fasteners used to attach the device to the steel fixture and the anchor bolt, that attaches the device to the test bed, may be higher strength than specified. However, they are required to be the same diameter as specified and, if a nut and washer are used, they are to have the same bearing area as specified for the field installation. If compression testing is performed, it is also required that the bolt, nut and plate washer be of the same dimension as used in the end-use application. Also, for compression testing, it is required that the maximum unbraced length of the anchor bolt be per the manufacturer’s recommendations and reported.

The device that is to measure the deformation is to be attached to the steel fixture above the hold-down. It is to measure the displacement that occurs between the steel fixture and the top of the anchor bolt. This will include fastener slip and hold-down deformation. An additional reference point for a displacement device could be at the top of the hold-down, such as a horizontal plate tack welded to the top of the hold-down, so as to isolate the hold-down device deformation to compare to the deformation recorded in the assembly test.

**Hold-down Assembly Test**

The hold-down assembly test requires the hold-down device be attached to a cold-formed steel member(s) that it will anchor to a supporting member(s), as shown in Figure 4a, and this is to determine the strength and deformation of the entire hold-down connection assembly. Similar to the hold-down device test for tension load testing, the hold-down is required to be installed a minimum of 1” above the test bed unless it is required to be installed in the field to a rigid structural steel or concrete base, in which case it may be attached directly on top of the test bed as shown in Figure 4b. It may be required to test the hold-down raised higher than 1” if the hold-down may contact the test bed prior to failure such as through seat rotation. If a hold-down is tested directly on the test bed, the anchor bolt should be instrumented so that the force to the anchor bolt can be measured and compared to the applied force as some hold-downs may amplify the applied force to the anchor bolt due to prying. This anchor bolt force information is needed by the designer so that the anchorage may be properly designed and detailed.

The attachment of the hold-down to the cold-formed steel member(s) is to be as it will be in the end-use application. This is inclusive of the specified weld or fastener material and dimensions, the quantity of welds or fasteners, the tightness of the bolt nut, the spacing of weld or fasteners, and the end and edge distances provided for the welds or fasteners. As in the hold-down device test, the anchor bolt may be higher strength than specified, but it is to be the same diameter as specified and, if a nut and washer are used, they are to have the same bearing area as specified for the field installation. If compression testing is performed, it is also required that the bolt, nut and plate washer be of the same dimension as used in the end-use application. Also, for compression testing, it is required that the maximum unbraced length of the anchor bolt and the gap between the cold-formed steel member(s) and the test bed, if occurs, be per the manufacturer and reported. The device that is to measure the deformation is to be attached to the cold-formed steel member(s) above the hold-down. It is to measure the displacement that occurs between the cold-formed steel member(s) and the top of the test bed.

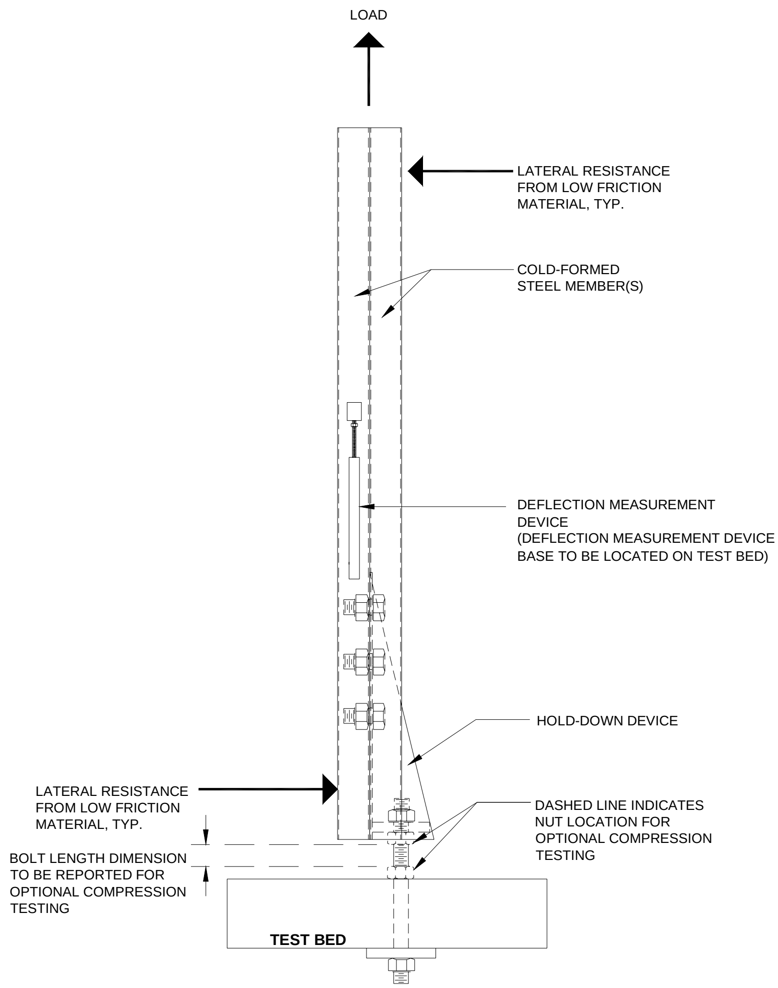


Figure 4a – Raised Tension Load Test Set-up
for a Single Hold-down Assembly

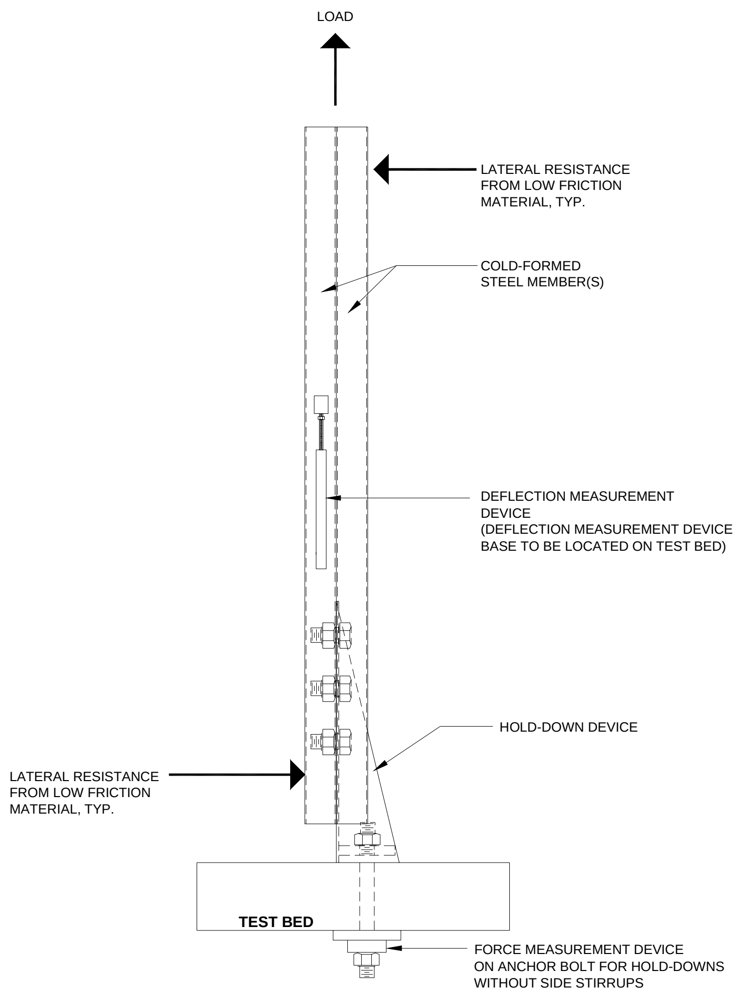


Figure 4b – Flush Tension Load Test Set-up
for a Single Hold-down Assembly

This will include fastener slip, fasteners to cold-formed steel member(s) bearing deformation, hold-down deformation, and anchor bolt elongation. In addition, the test standard requires that the cold-formed steel member(s) be a minimum of 1” above the test bed, even when the hold-down is installed flush to the test bed.

This is to ensure that the hold-down compression strength is not relying on the compression strength of the attached cold-formed steel member(s) as actual field built conditions may differ from that in the test laboratory.

**Test Procedure**

It is not permitted to preload the test assembly as hold-downs are typically used to resist short-term loads from wind and seismic events and, therefore, seating due to long term loads may not occur prior to an event. The load is to be applied at a certain rate and in the direction that is expected in the actual condition (ie; tension, compression). The load and displacement are to be measured to produce a load-displacement curve. A minimum of eight reported displacements, spaced throughout as evenly as possible and not grouped just at the beginning or middle or end of the test, is required prior to the displacement test limit.

**Evaluation of Data**

It is required that every test be used unless a valid reason to exclude it is given. The test data is to be analyzed and the design or available strength is the lowest of either the available strength determined using the specification Section F1 [8] or, for hold-downs in shear walls or that otherwise contribute to the story drift, the load at the deflection limit given in the test standard. If the hold-down device fails, the statistical values shown in Table F1 that are to be used in the Section F1 equation used to determine the resistance factor are to be those listed for "Structural members not listed above".

The strength of the device is the lowest of (1) either the device or the assembly test, (2) the strength of the cold-formed steel member(s) as determined by the specification [8], (3) the strength of the fastening of the hold-down to the cold-formed steel member (connection) as determined by the specification [8], or (4) the strength of the fastener or weld itself (connector) as determined by the specification [8]. The hold-down assembly test shall be used to determine the hold-down strength when the fasteners used to attach the hold-down to the cold-formed steel members are not shown in the specification [8] or if the fastener specified is in the specification [8], but some aspect of it (i.e.; spacing, edge distance, material, etc.) does not conform to all the specification [8] fastener requirements.

The specification [8] Section F1.1(c) requires reductions when the tested material strength is greater than the specified material strength for the hold-down device or the hold-down device and the cold-formed steel members it's attached to in the assembly test. The material strength reductions are not cumulative and the larger reduction is to be used. In addition, a reduction is required when the thickness of the hold-down or the cold-formed steel members is greater than the minimum specification. These reductions are computed simply by dividing the specified value by the tested value.

The displacement of the hold-down is to be determined from the hold-down assembly test. The displacement limit for hold-downs in shear walls or that otherwise contribute to the story drift is prescribed as 0.185 inch and 0.25 inch for the hold-down device test and for the assembly test, respectively. It is a strength level displacement limit as the story drift is to be computed at strength level in accordance with ASCE7 Section 12.8.6 [7]. The load at these displacements are to be multiplied by 0.7, seismic strength to ASD conversion factor from ASCE7 load combinations, to determine the deflection limit for ASD as most light-frame design is performed using ASD. Other limits might be required by building jurisdictions or justified for other conditions.

The allowable strength design (ASD) displacement limit of 0.125 inch (0.185 inch LRFD limit) for the hold-down device itself has been used by some as a displacement limit for hold-downs in shear walls to limit the uplift of the bottom corner of the shear wall so as not to overly tax the sheathing to fastener connection. The 0.1875 inch limit (0.25 inch LRFD limit) takes into account fastener slip and bearing deformation, that might occur in typical hold-down connections, in addition to the device deflection in typical hold-down connections.

In addition, limiting the hold-down deflection is useful in that it reduces the hold-down contribution to the horizontal top of wall drift. The vertical deflection of the hold-down is one of several contributors to the horizontal top of wall drift. It is determined by multiplying the vertical hold-down displacement by the aspect ratio of the shear wall as shown in Figure 1.

For a hold-down that has a displacement of 0.125 inch at ASD in a 2:1 aspect ratio wall, this would equate to a 0.25 inch horizontal top of wall displacement just due to the hold-down device itself. This is over half of the permissible seismic story drift, in accordance with ASCE7 [7] Table 12.12-1, for an 8 foot tall shear wall. The shear wall deflection equation in AISI S213 [6] C2.1.1 is a four part equation with the horizontal top of wall displacement contribution due to the hold-down, as shown in Figure 1, as just one part.

**Test Report Requirements**

The standard requires that the test report contain a description and drawing of the hold-down, inclusive of dimensions in both the device and assembly tests and description of the attached cold-formed steel members in the assembly tests. The tested and specified material properties for the hold-down and the welds or fasteners used must also be reported. If the cold-formed steel members were modified in some manner in the assembly tests, this information must also be provided.

Information on the attachment of the hold-down to the steel fixture and the cold-formed steel members must be given. This is inclusive of the specified weld or fastener material and dimensions, the quantity of welds or fasteners, the spacing of weld or fasteners, the end and edge distances provided for the welds or fasteners, and if the threads of the fastener were included in the shear plane between the hold-down and the steel fixture in the device test.

The report is to include a detailed drawing of the test setup indicating load direction and point of application. It is also to include the rate of loading, location of the displacement measuring devices, photographs of the test setup, and noting any deviations from any test requirements for the test fixture, for the device and assembly tests, and/or for the test procedure. It is to also include the load-displacement curves for each hold-down test.

It is required to include the load values obtained by the devices as well as a description of the failure mode(s) and its location. An example would be noting net tension fracture at the lowest bolt hole in the hold-down device. The behavior of the device during load application is also to be noted as well as including photographs of the failure.

**Hold-down Test Using New Standard**

Hold-down assembly tension tests were performed using the new AISI hold-down test standard on Simpson Strong-Tie hold-downs, obtained from


Figure 5 – Raised hold-down Assembly Tension Test Setup – Side

production stock, attached to two 350S162-54 structural cold-formed steel studs. The hold-downs are fabricated from steel 118 mil thick and comply with ASTM A 653 GR33. The raised hold-down assembly tension test was setup in accordance with the AISI test standard as shown in Figure 4a. A picture of the test setup is shown in Figures 5 and 6. The failure was several of the hold-down screws shearing at the connection to the cold-formed steel studs. The picture of the test failure is shown in Figure 7.

Figure 6 – Raised hold-down Assembly Tension Test Setup – Front

Figure 7 - Hold-down Assembly Tension Test Failure – Screw Shear

Three tests of the same setup were performed and yielded ultimate tension load values of 28,613 lbs, 27,042 lbs, and 28,358 lbs. The average ultimate value, or nominal strength, is then 28,004 lbs with a small coefficient of variation of 0.03. Based on the hold-down screw shear failure failure, the statistical values used from Table F1 to compute the resistance factor are for "Shear Strength of Screw". Using a target reliability index, $\beta_o$, of 3.5 as the connection was the failure, the specification Chapter F calculation yields a resistance factor of 0.59 and an ASD safety factor, $\Omega$, of 2.71. Figure 8 summarizes the strength and deflection test measurements as well as the failure mode for these tests.

| Description | Average | Test 1 | Test 2 | Test 3 |
|---|---|---|---|---|
| Ultimate Load | **28004** | 28613 | 27042 | 28358 |
| Failure | - | Screws sheared | Screws sheared | Screws sheared |
| Load at 1/4" | **17538** | 15989 | 19213 | 17412 |
| Load at 1/4" / 1.4 | **12527** | 11421 | 13724 | 12437 |

Figure 8 – Raised Hold-down Assembly Tension Test Results Summary

The average load at the ¼" deflection limit was 17,538 lbs and 12,527 lbs when multiplied by 0.7 to determine the ASD deflection limit load. Figure 9 shows the average load-displacement curve for these tests. The hold-down uses 18 - #14 self-tapping screws and the specification screw calculation yields a shear strength of 23,675 lbs. Therefore, available strength (ASD) is 10,334 lbs governed by the tested strength divided by the safety factor.

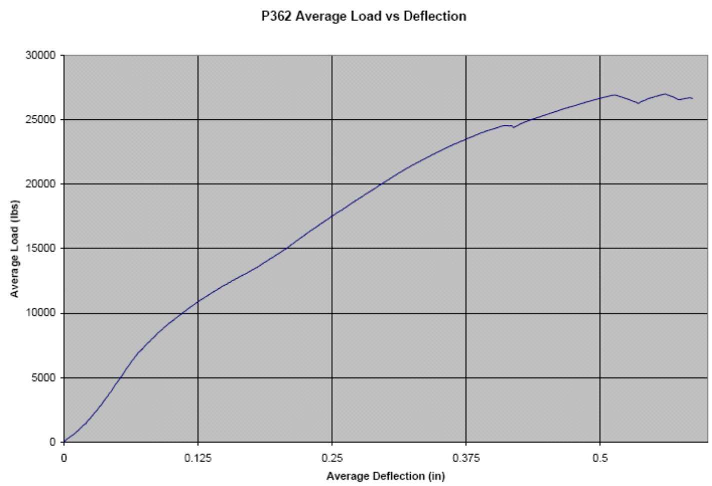


Figure 9 – Raised Hold-down Assembly Tension Test Average Load-Displacement Curve

Section 10.1 of the test standard requires the data be evaluated in accordance with Section F1 of the specification [8] and this section requires load reductions when the steel strength or base metal thickness of the hold-down or the attached members, in this case the structural studs, exceeds the minimum specification. The hold-down specified base metal thickness, yield strength, and tensile strength are 0.1275 inch, 33 ksi, and 45 ksi, respectively. The average base metal thickness, yield strength, and tensile strength for the hold-downs in these tests were 0.1299 inch, 47.1 ksi, and 57.2 ksi, respectively. The 350S162-54 specified base metal thickness, yield strength, and tensile strength are 0.0538 inch, 50 ksi, and 65 ksi, respectively. The average base metal thickness, yield strength, and tensile strength for the studs in these tests are 0.0545 inch, 64.7 ksi, and 71.7 ksi, respectively.

| Test Load Reduction for Steel Overstrength and Thickness | | |
|---|---|---|
| **Description** | **Hold-down** | **Stud** |
| Hold-down Ultimate (lbs) | 28004 | |
| Fy-spec,min (ksi) | 33 | 50 |
| Fu-spec,min (ksi) | 45 | 65 |
| Fy-test,avg (ksi) | 47.1 | 64.7 |
| Fu-test,avg (ksi) | 57.2 | 71.7 |
| Fy Reduction | **0.700** | 0.773 |
| Fu Reduction | 0.787 | 0.907 |
| t-spec,min (in.) | 0.1275 | 0.0538 |
| t-test,avg (in.) | 0.1299 | 0.0545 |
| t Reduction | **0.9815** | 0.9872 |
| Ultimate/SF (lbs) | 10334 | |
| Adjusted Ult. (lbs) | 19245 | |
| Adjusted Ult./SF (lbs) | **7101** | |
| Effective SF | **3.94** | |

Figure 10 – Raised Hold-down Assembly Tension Test Material Properties, Reduction Factors, and Effective Safety Factor Summary

The hold-downs were fabricated from the same coil of steel as were the cold-formed steel studs, otherwise, material property tests would have to be performed for each test. Three tests on the steel from the hold-downs and three tests on the steel from the cold-formed steel studs were performed to determine the average yield and tensile strengths. In addition, ten thickness measurements were made for the hold-downs and ten for the studs to determine the average base metal thickness. The yield strengths, tensile strengths, base metal thicknesses, and steel strength reduction factors for the hold-down and the cold-formed steel members are summarized in Figure 10.

A strength reduction factor of 0.70, based on material strength over the minimum specification, in combination with a reduction factor of 0.98, based on thickness over the minimum specification, if applied to the design strength would result in an adjusted available strength of 7,101 lbs. A case might be made that the yield strength, Fy, reduction should only be taken if yielding is the governing failure mode rather than taking the larger of the yield or tensile strength reductions in accordance with the specification [8] Section F1.1(c). In this test the failure was shearing of the screws themselves and so, if the Fu reduction was taken instead, this would result in a 0.79 load reduction factor, in addition to the 0.98 reduction factor for thickness, for which the adjusted available strength would be 7,984 lbs.

Another observation is that the calculated nominal shear strength determined in accordance with S100 Section E4.3.1, is 71,025 lbs and quite high compared to the test average ultimate load of 28,004 lbs. This might justify that no strength reduction factor be used as fastener bearing failure would not occur even if the studs and hold-down were fabricated from steel with strength close to the minimum specification. This has been shown to be true in tests with hold-down and cold-formed steel member strength close to specified.

When hold-down tests are performed using steel with strengths close to the minimum specifications, which is very difficult to find, the load values typically go up greater than the inverse of the conservative strength reductions using $Fu\text{-}_{test}$ divided by $Fu\text{-}_{specified}$ and $Fy\text{-}_{test}$ divided by $Fy\text{-}_{specified}$. In this case, the safety factor required by the specification was 2.71 and, for the production hold-downs from stock tested, the approximate safety factor is 3.94 (28006/7101). So production hold-downs typically yield higher safety factors than required by the specification due to the fact that the steel supplied to fabricate these hold-downs is always stronger than the minimum specification.

## Conclusion

It is necessary to develop test standards to provide uniform testing procedures to better evaluate and compare the strength and displacement behavior of devices that cannot be simply calculated using the AISI specification or the COFS standards due to their complexity and the complexity of the load path through them. The AISI COS new Test Standard for Hold-downs Attached to Cold-Formed Steel Structural Framing was developed in response to this need. It was also developed in recognition of the importance these devices have in the proper functioning of cold-formed steel framing lateral force resisting systems, and thus the overall structure.

**References**

1. AISI Test Standard for Hold-downs Attached to Cold-Formed Steel Structural Framing (S913), 2008.
2. AISI Cold-Formed Steel Manual, 2002.
3. AISI North American Standard for Cold-Formed Steel Framing – General Provisions, AISI S200, 2007.
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7. ASCE7 Minimum Design Loads for Buildings and Other Structures including Supplement No. 1, 2005.
8. AISI North American Specification for the Design of Cold-Formed Steel Structural Members (S100), 2007.