

Report on Laboratory Testing of Anchor Bolts Connecting Cold-Formed Steel Track to Concrete with Minimum Edge Distances

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PREFACE

New design provisions for determining the capacity of connections using anchor bolts to fasten cold-formed steel track to concrete foundations in Appendix D of ACI 318, *Building Code Requirements for Structural Concrete*, result in significantly reduced capacities when compared to historical values and legacy code requirements. The state of knowledge regarding this connection is ambiguous and does not support such a large reduction for a common assembly.

This research project was undertaken to evaluate the behavior of the cold-formed steel track-to-concrete anchor bolt connection, establish whether ductile steel failure modes rather than concrete failure modes control the capacity of the connection, and determine if the use of AISI bolt-bearing design values are appropriate for the connection.

The results of this study were used to substantiate public comments that were submitted by AISI and SFA on proposal S167-09/10 to modify the ICC *International Building Code*. It is anticipated that the results of this study will also be submitted to the AISI Committee on Framing Standards for consideration in a future edition of AISI S213.

Report on Laboratory Testing of Anchor Bolts Connecting Cold-Formed Steel Track to Concrete with Minimum Edge Distances

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Abstract

The 2009 edition of the *International Building Code* requires that ACI 318 Appendix D design provisions be used for the calculation of the capacity of anchor bolts fastening cold-formed steel (CFS) bottom track sill plates to concrete foundations. As an alternate to designing the steel attachment or the anchor element to undergo ductile yielding, a multiplier of 0.4 would apply to the shear strength of the concrete failure mode. When specifically applied in Seismic Design

Categories (SDC) C, D, E, and F, this method results in significantly reduced capacity for this connection as compared to historical values found in legacy code requirements. The state of knowledge regarding this connection is ambiguous and does not support such a large reduction for a common assembly particularly at small distance parallel to a free edge.

This experimental testing demonstrates that actual capacities of the track-to-concrete anchor bolt connection far exceed those historically used for design, supporting the use of AISI bolt-bearing design values for the connection in lieu of those determined in accordance with ACI 318, Appendix D. The experimental data demonstrates that ductile steel failure modes rather than concrete failure modes limit the capacity of the connection; therefore, there is no need to require the reduction in the capacity of the connection based on concrete strength as specified in ACI 318, Section D.3.3.6. This test program demonstrates that the connection of CFS tracks from 33 mils up to 68 mils and with edge distances as small as 1.75" satisfy the ductile yielding requirement of ACI 318, Section D.3.3.5.

Introduction

Seismic force resisting systems (SFRS) for cold-formed steel (CFS) light-framed buildings typically comprise shear walls with anchor bolts located at the edge of concrete foundations. These connections often have an edge distance as little as 1-3/4" from the bolt center to the face of the concrete slab or footing.

Engineers have historically anticipated the controlling failure of this connection to occur between the anchor bolt and the CFS track. However, design capacities for break-out strength of the anchor bolt in shear, determined in accordance with ACI 318 (ACI, 2005 and ACI, 2008) Appendix D, are significantly reduced when compared to historical values found in legacy code requirements in Seismic Design Categories C, D, E, and F (1999 UBC Table 19-D). ACI 318 requires a reduction in concrete break-out design capacity unless connections are ductile, but application of ductile provisions to the entire CFS track-to-concrete connection (as opposed to the anchor bolt only) are not currently permitted within ACI 318.

Lacking specific test data to substantiate the need for the reduced design capacities for anchors in concrete for a typical CFS track to concrete connection loaded parallel to the edge (per ACI 318, Appendix D), the AISI/SFA/SSMA Project Monitoring Task Group (PMTG) undertook this study to characterize typical anchor bolted connections through an experimental testing program with the following goals:

- Establish test data for the connection capacity when loaded parallel to the edge of slab;
- Determine whether the connection exhibits ductile steel behavior;
- Propose rational design capacities for the connection based on test results.

A total of 21 tests were performed. All tests were single-bolt tests in CFS tracks connected to concrete with post-installed steel anchor bolts.

Test Specimens

Figure 1 depicts a typical cross section of the specified test specimen. Seven configurations were tested in triplicate. Table 1 summarizes the parameters for each of the seven configurations.

LOADING FIXTURE NOT SHOWN FOR CLARITY

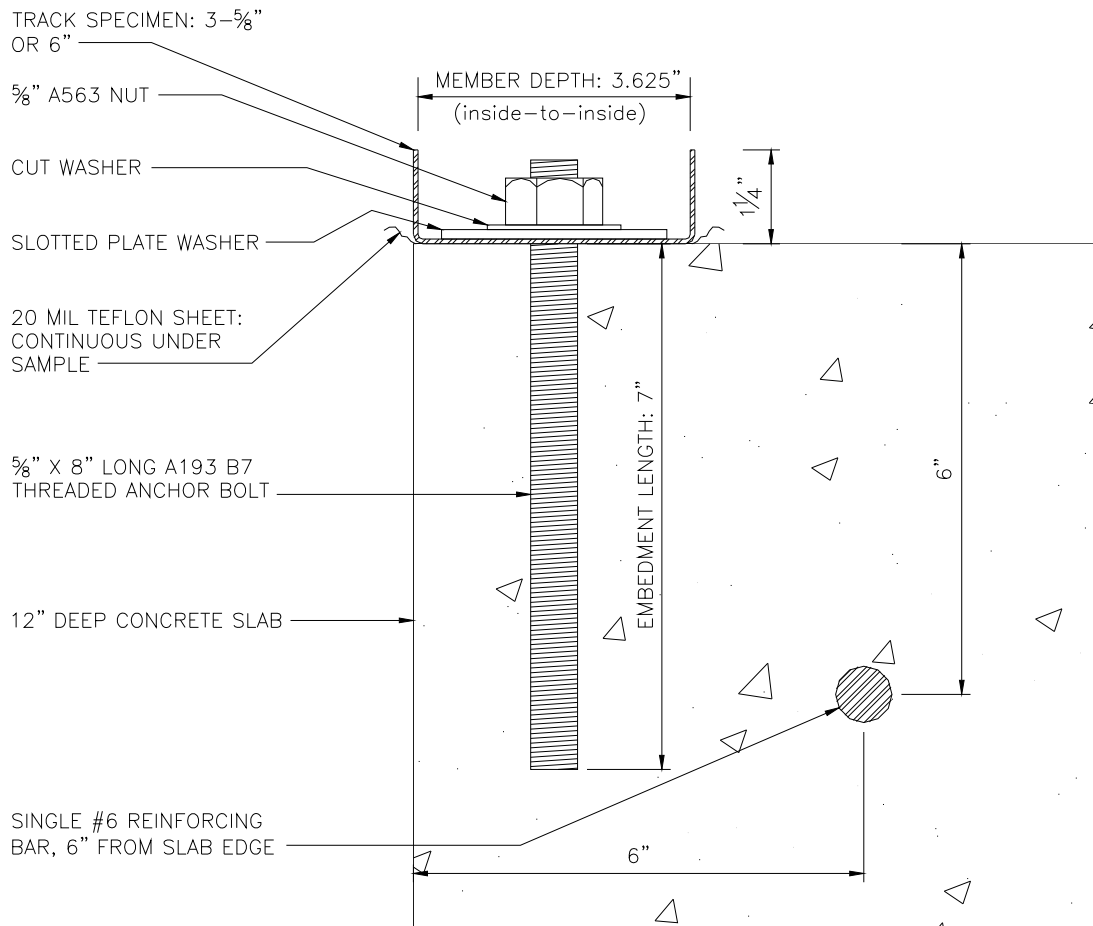


Figure 1: Typical Cross Section of Test Specimen

Table 1: Summary of Tests

Test Series Number	1	2	3	4	5	6	7
Track Thickness (mils)	33	68	68	68	68	68	68
Track Depth (in)	3-5/8	3-5/8	3-5/8	3-5/8	3-5/8	3-5/8	6
Track Grade (ksi)	33	50	50	50	50	50	50
Bolt Diameter (in)	5/8	5/8	5/8	5/8	5/8	5/8	5/8
Embedment (in)	7	7	7	7	7	7	7
Track Hole Size (in)	11/16	11/16	11/16	11/16	11/16	11/16	11/16
Washer Type	plate	standard	plate	plate	plate	plate	plate
Edge Distance (in)	away	away	away	away	1-3/4	1-3/4	2-3/4
Friction/Slip	slip	slip	slip	slip	slip	slip	slip
Loading Protocol	mono	mono	mono	cyclic	mono	cyclic	cyclic

The anchors tested were post-installed adhesive anchors. This was deemed appropriate by the PMTG, because previous testing by Hilti has shown no statistically significant difference in the behavior between cast-in-place and post-installed adhesive anchors where the testing is only intended to evaluate shear behavior. Concrete specimens were tested “as-cast,” without the intentional creation of cracks in the test specimen, which was consistent to similar tests on wood sill plates (SEAONC, 2009).

CFS tracks tested were nominal 3-5/8” and 6” sizes. Anchor bolts were located in the track web to achieve the target edge distances (measured from centerline of the anchor to the face of the concrete foundation) of 1-3/4” and 2-3/4”. It should be noted that centering these holes in the web of the CFS track would have resulted in slightly larger edge distances.

Component Descriptions

Concrete: A compressive strength (f'_c) of 2500 psi to 3000 psi was specified for the tests to represent concrete typical of light-frame construction. This is consistent with what was considered for similar tests on wood sill plates (SEAONC, 2009). Cylinder tests, reported in Appendix D, showed actual f'_c values of 2650 psi. The 9' x 7' concrete slab had a 12” thickness. Reinforcement consisted of #6 rebar at mid-height, placed 6” in from the slab perimeter on all four sides. Consequently, the rebar was placed approximately 4-1/4” away (also, in a direction away from the edge) and approximately even with the embedded end of the 5/8” anchor installed 1-3/4” from the slab edge.

CFS Track: Figure 2 depicts the cross section of the typical CFS track section that was tested. CFS track was of nominal 3-5/8” and 6” sizes, which means the web depth (inside to inside of flange) was 3-5/8” or 6”. Material was standard galvanized steel with a G60 coating. Table 1 reports the thickness, depth and grade (i.e, specified yield strength, F_y) for each specimen. Mechanical properties of the CFS track were verified by laboratory tests and are reported in Appendix D. Material was tested in “as received” condition. As noted in Table 1, each test utilized an 11/16” diameter drilled hole that was located in the web of the CFS track.

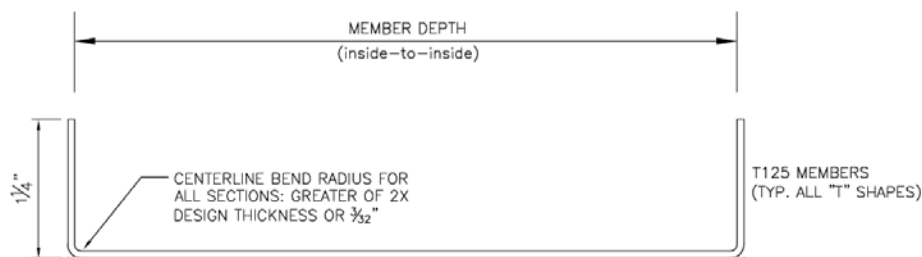


Figure 2: Cross Section of CFS Track

Anchor Bolts: Anchor bolts, all threaded rods, were ASTM A193 B7 compliant (105 ksi yield and 125 ksi tensile), 5/8” diameter, post-installed adhesive anchors (Hilti product reference HIT-RE 500-SD Epoxy Adhesive Anchoring System). Anchor bolts were 8” length with an embedment length of 7” in the concrete. No reinforcement was located coincident with the bolt locations. Anchor bolts were located with an edge distance as listed in Table 1.

Anchor Bolt Washers: Anchor bolt washers were either standard cut washers or plate washers, as noted in Table 1. Plate washers (Simpson Strong-Tie product reference BPS5/8-3) were prefabricated square steel plates (0.229"x3"x3"), uncoated, with a diagonal slotted hole.

Anchor Bolt Nuts: Anchor bolt nuts were ASTM A563 compliant, standard 5/8" diameter. All tests were run with the nut tightened to a torque in a range of 5 to 9 foot-pounds, to eliminate any gaps between the CFS track and surface of the concrete and to ensure that the CFS track loaded the bolt just above the concrete surface.

Membrane: An isolation membrane between the CFS track and the concrete was installed on all tests, as noted in Table 1. The membrane was comprised of a single, 0.020" thick Teflon® sheet, to approximate an idealized "frictionless" plane. Tests utilizing the membrane are designated "slip" in Table 1.

Test Set-Up and Procedure

All tests were conducted at the laboratories of Hilti North America in Tulsa, Oklahoma between February 2010 and April 2010. Figure 3 shows the set-up for a typical test.

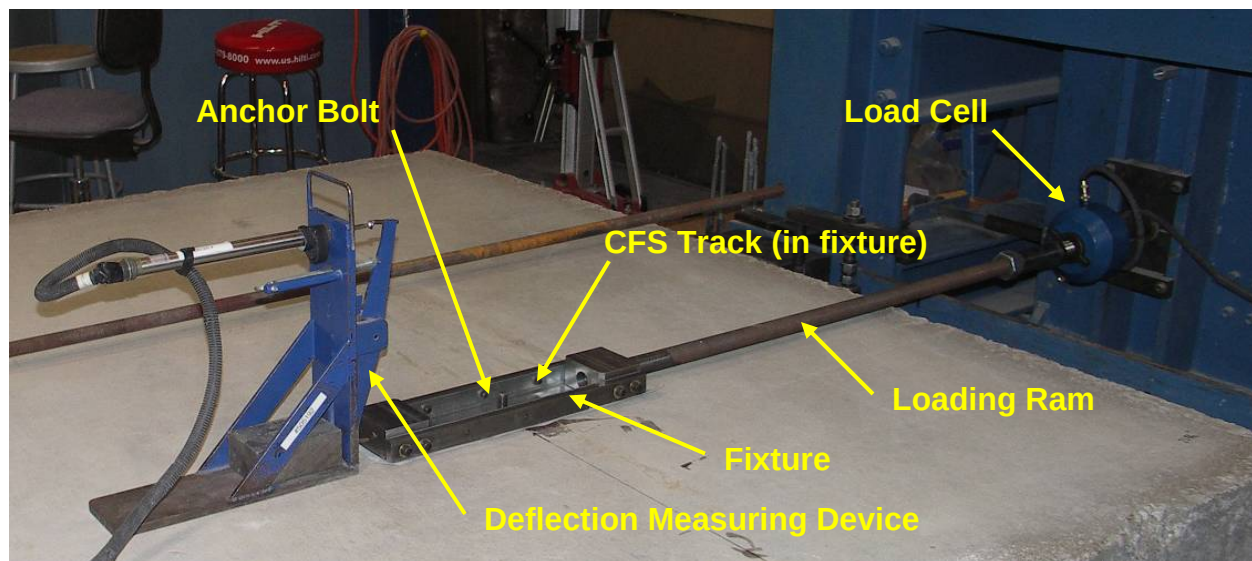


Figure 3: Typical Test Set-up Away From Slab Edge (Set-up at Edge Similar)

Monotonic tests were performed at a loading rate of between 1 and 3 minutes to failure. Cyclic tests were conducted with a load-based cyclic testing protocol (sine wave) at a frequency of 0.1Hz (1 cycle every 10 seconds). Loading for the cyclic tests was five (5) repetitions at six (6) different and increasing percentages (67, 75, 85, 95 100 and 110 percent) of the onset of deformation load (4,500 lb) that was determined from the monotonic tests for the 68-mil CFS track (Series 2, 3 and 5). For additional details on loading, see Appendix B.

Each anchor bolt was tested as a single element connecting an 18" long CFS track to the larger concrete "foundation" element. Figure 4 shows the fixture that Hilti fabricated to introduce loads into the CFS track section. A schematic of the fixture is shown in Appendix A. The fixture was attached to the CFS track with six (6) 1/4" cap screws from the track to the side-plates and eight (8) 5/16" cap screws through the side-plates and track flanges directly into the end blocks. No intentional vertical load was introduced into the test specimen; although vertical movement was monitored at the end adjacent to the loading ram.



Figure 4: Close-up View of Test Fixture (Prior to Installation of Washer and Nut)

Displacement was measured at the end away from the loading ram. All loads and displacements were collected via a digital data acquisition system. Sampling rate was the A/D conversion of measurements (1,000 Hz). The data was parsed as it was logged. For cyclic conditions, only the minimum and maximum data points for load and displacement were recorded.

Monotonic Test Results

The detailed results for the monotonic tests (Series 1, 2, 3 and 5) are found in Appendix A. The results are summarized in Table 2, which provides a comparison with predicted values that are calculated in accordance with the bolt bearing provisions of AISI S100 (AISI, 2007). Table 2 also includes the calculated AISI design values.

Table 2: Summary and Comparison of Monotonic Test Results

Test Series Number	1	2	3	5
Ultimate Load (lbs) ¹	2,860	7,400	7,550	7,490
Predicted Strength (lb) ²	1850	5,570	5,570	5,570
Tested/Predicted Ratio	1.24	1.33	1.36	1.34
AISI Design Strength (lb) ³	740	2,228	2,228	2,228

Notes:

- 1) The ultimate load is the average ultimate load of the three (3) tests in the series.
- 2) The predicted strength is the calculated nominal strength for a bolted connection determined in accordance with AISI S100 for a bearing limit state with a single washer and nut.
- 3) The AISI design strength is the nominal strength (predicted strength) divided by a safety factor of 2.50.

Comparison of the ultimate load to predicted strength for the monotonic tests (Series 1, 2, 3 and 5) shows that the provisions of AISI S100 are conservative in the range of 24 to 36 percent. It should be noted that the predicted strength for this comparison was based on the measured tensile strength for the CFS track, as reported in Appendix D.

In addition, comparison of the ultimate load for monotonic tests of the 68-mil CFS track away from the edge of concrete and close to the edge of concrete (Series 3 vs. 5) shows that there was little-to-no influence of the reduced edge distance.

For the 33 mil and 68 mil track with a plate washer (Series 1 and 3), it was observed that the anchor effectively carved a clean slot into the track with no transverse tearing or fracture, as shown in Figure 5. However, for the 68 mil track with the standard cut washer (Series 2), it was observed that there was some transverse tearing, as shown in Figure 6.



Figure 5: Monotonic Test with Plate Washer