31 May 2010

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

American Iron and Steel Institute

research report

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

RESEARCH REPORT RP10-3

2010

American Iron and Steel Institute

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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

May 31, 2010

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- Ben Schafer, The Johns Hopkins University
- John Silva, Hilti North America

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- John Silva

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- Sam Hensen

Steel Stud Manufacturers Association (SSMA)

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 D3.3.5.

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.

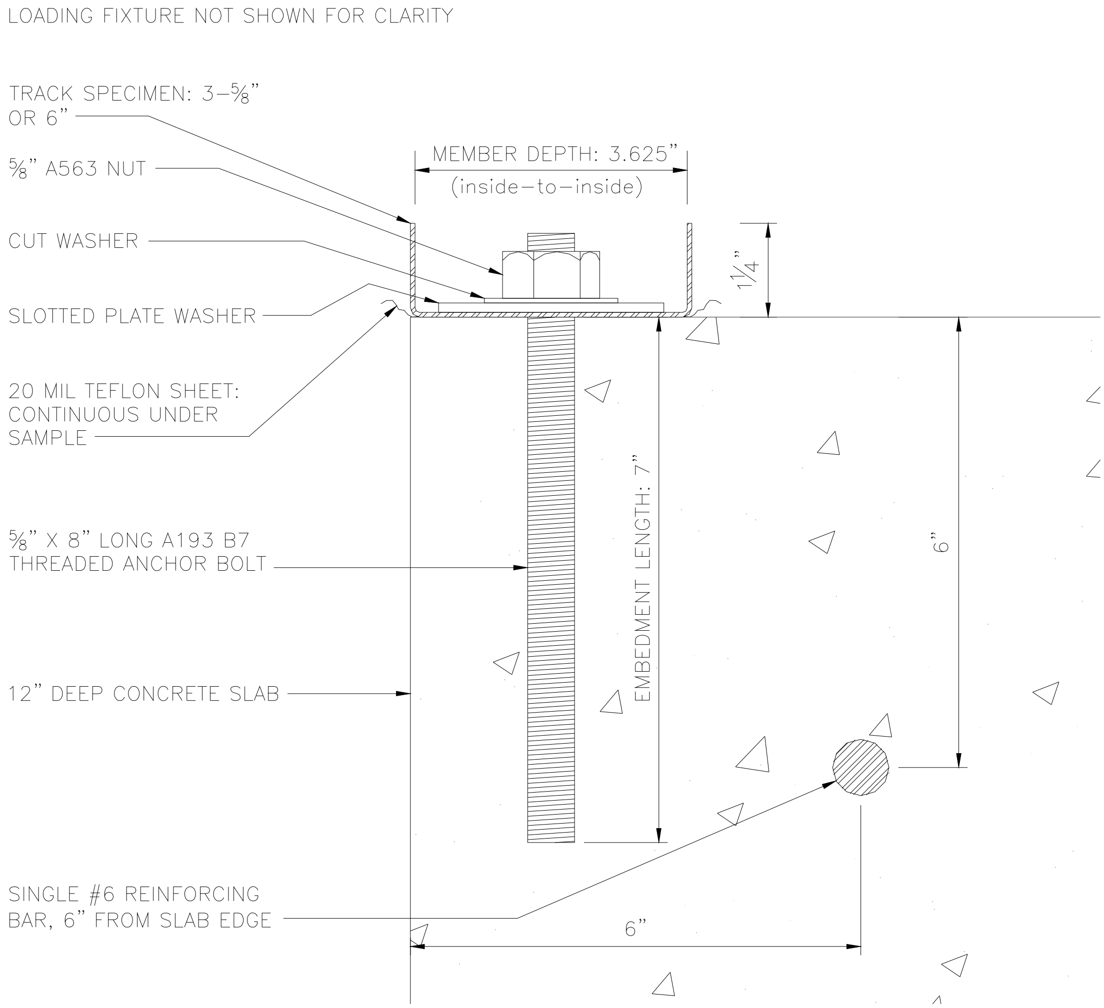


Figure 1: Typical Cross Section of Test Specimen

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.

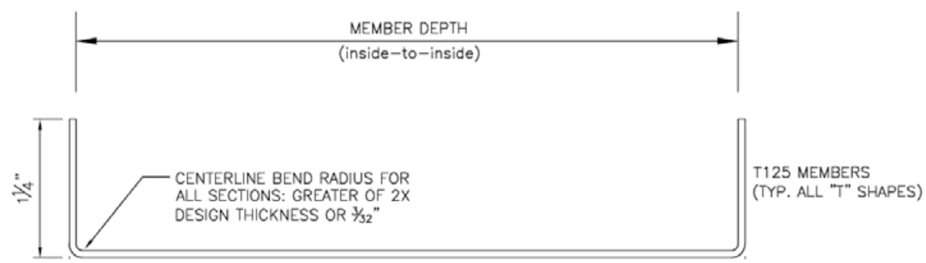


Figure 2: Cross Section of CFS Track

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.

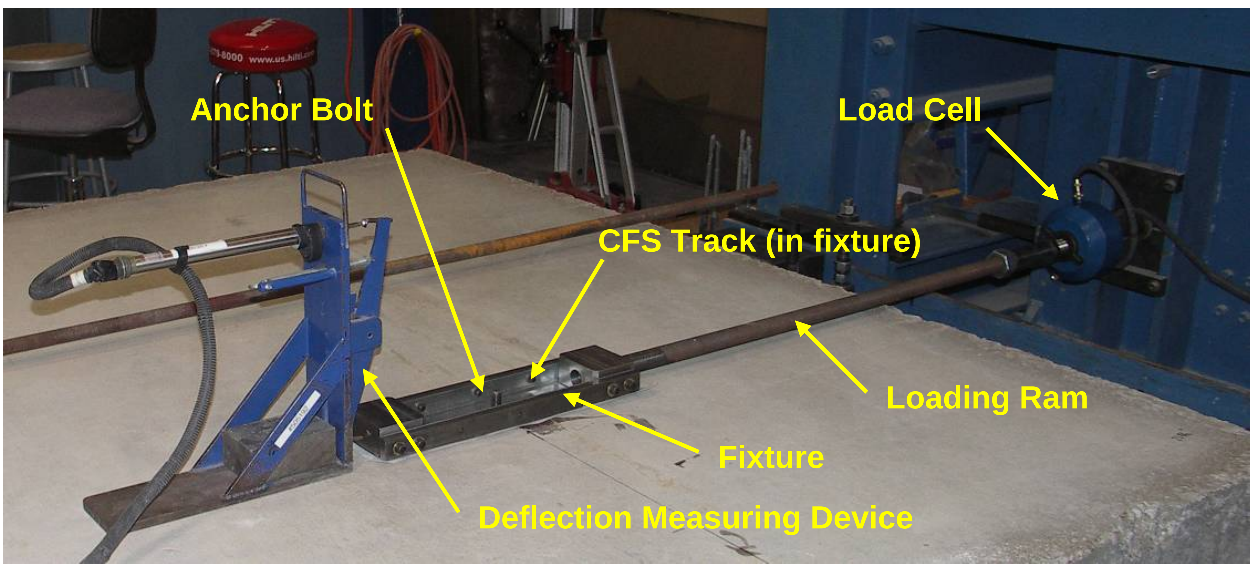


Figure 3: Typical Test Set-up Away From Slab Edge (Set-up at Edge Similar)

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.

<u>Monotonic Test Results</u>

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

Figure 6: Monotonic Test with Standard Cut Washer

Cyclic Test Results

The detailed results for the cyclic tests (Series 4, 6 and 7) are provided in Appendix B. The results are summarized in Table 3, which provides a comparison with the calculated AISI design values.

Table 3: Summary of Cyclic Test Results

Test Series Number	4	6	7
Maximum Applied Load (lbs)[1]	4,875	4,850	4,825
AISI Design Strength (lbs)[2]	2,228	2,228	2,228
Ratio[3]	2.19	2.18	2.17

Notes:
1) The maximum applied load is the average maximum load for each of the three (3) tests in the series. For these cyclic tests, the maximum applied load for each test in a series was calculated as the average of the positive and negative value from the test.
2) The AISI design strength is calculated for a bolted connection determined in accordance with AISI S100 for a bearing limit state with a single washer and nut.
3) The ratio is the maximum applied load divided by the AISI design strength.

Video recordings confirmed that during the test the track moved until the edge of the hole came in contact with the bolt, and then the bolt began to deflect elastically. As the cyclic load levels were increased, the CFS track began to deform at the location of bolt bearing. See figures in Appendix C. Upon the reversal of load, the bolt returned to its initial un-deformed position while the track continued to move until the opposite edge of the hole came in contact with the bolt. Then, the bolt began moving elastically. As the cyclic load levels were increased, the CFS track began to deform at the location of bolt bearing. Upon the reversal of load, the bolt again returned to its initial un-deformed position while the track continued to move until the opposite edge of the hole came in contact with the bolt. This process continued until the test was halted. No plastic deformation of the bolt, washer or nut was noted. Additionally, no damage to the concrete was observed in any of these tests. Permanent deformation was isolated solely to the CFS track.

Comparison of the maximum load for cyclic tests of the 68-mil CFS track away from the edge of concrete and close to the edge of concrete (Series 4 vs. 6 and Series 4 vs. 7) shows that there was little-to-no influence of the reduced edge distance. In all cases the maximum load was achieved without anchor bolt or concrete distress or failure.

In addition, comparison of the maximum loads to the AISI design strengths demonstrates reserve capacity. The measured displacements demonstrate ductility.

Findings and Conclusions

This test program was designed to achieve the following primary goals:

1. **Establish test data for the connection capacity when loaded parallel to the edge.**

   It is evident that "bearing" of the CFS track represents the first and only material limit state. The connection assembly exhibited the following behavior phases:
   - initial take-up and displacement (connection assembly gets "seated")
   - elastic bolt bending combined with elastic deformation of the CFS track due to track bearing on the bolt
   - inelastic deformation of the CFS track due to track bearing on the bolt

2. **Determine whether the connection exhibits ductile steel behavior.**

   For the connection of CFS tracks ranging from 33 mil up to 68 mil and with edge distances as small as 1.75", the connection exhibited significant deformation capacity and ability to sustain loads as shown in the load-displacement curves in Appendixes B and C. The behavior is ductile.

3. **Propose rational design capacities for the connection based on test results.**

This experimental testing demonstrates that actual capacities of the track-to-concrete anchor bolt connection for CFS tracks ranging from 33 mil up to 68 mil and with edge distances as small as 1.75" 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 reduce the capacity of the connection based on concrete strength as specified in ACI 318.

In conclusion, the tests indicate that 5/8 inch diameter anchor bolts in CFS tracks attached at the edge of a concrete foundation exhibit ductile steel behavior and attain loads much greater than design strengths obtained using ACI 318, Appendix D, as required in the International Building Code (ICC, 2006 and ICC, 2009). Because the bolt/concrete interface showed no damage beyond the track limit state, a recommendation to obviate the calculation required in ACI 318, Appendix

D is warranted; the test data supports the design of this connection using the AISI bolt-bearing design values.

References

(ACI, 2005), *Building Code Requirements for Structural Concrete*, American Concrete Institute, Farmington Hills, MI, 2005.

(ACI, 2008), *Building Code Requirements for Structural Concrete*, American Concrete Institute, Farmington Hills, MI, 2008.

(AISI, 2007), AISI S100-07, *North American Specification for the Design of Cold-Formed Steel Structural Members*, American Iron and Steel Institute, Washington, DC, 2007.

(ICC, 2006), *International Building Code*, International Code Council, Washington, DC, 2006.

(ICC, 2009), *International Building Code*, International Code Council, Washington, DC, 2009.

(SEAONC, 2009), *Testing of Anchor Bolts Connecting Wood Sill Plates to Concrete with Minimum Edge Distances*, Structural Engineers Association of Northern California, San Francisco, CA, 2009.

Attachments

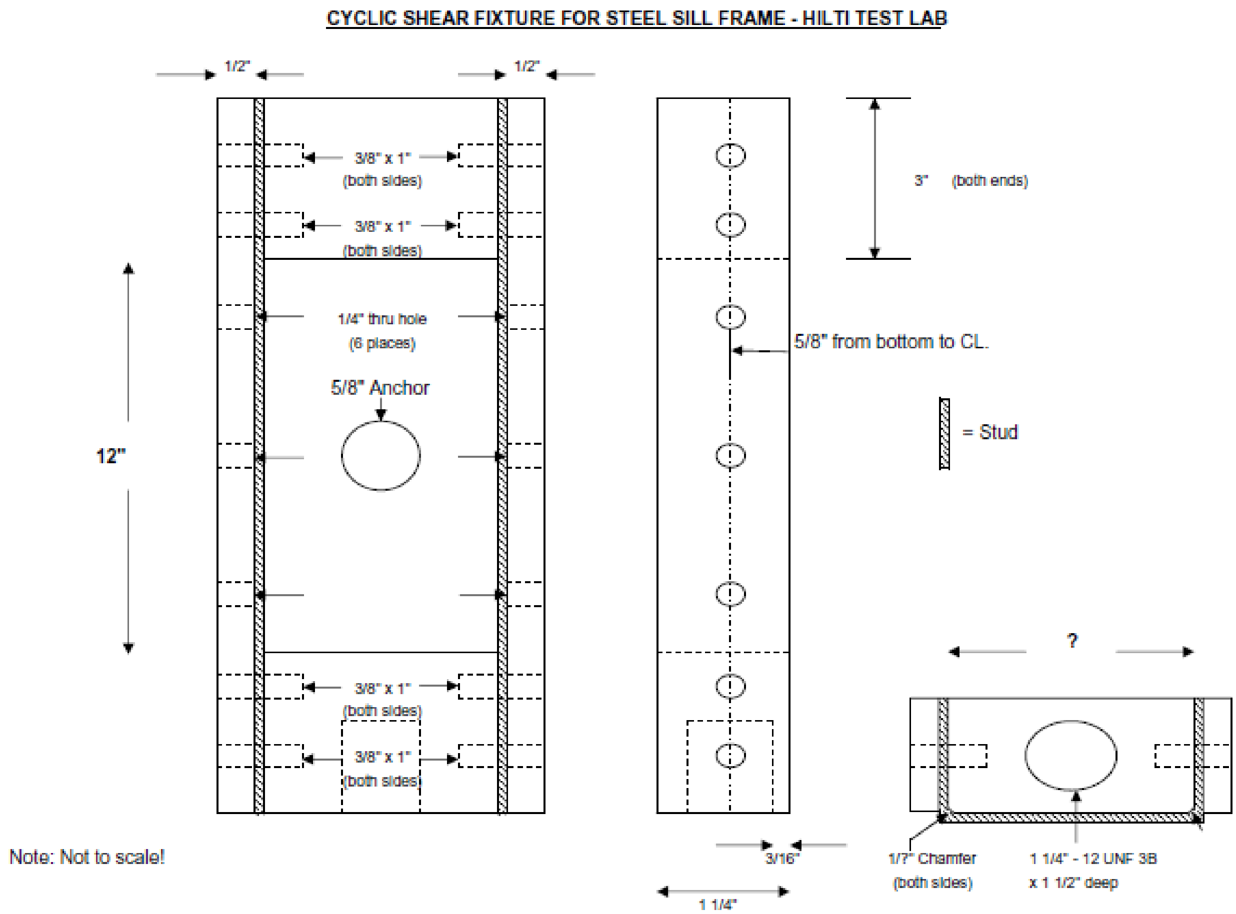
Attachment A - Schematic of Test Fixture

Attachment B - Monotonic Tests

Attachment C - Cyclic Tests

Attachment D - Material Property Tests

Appendix A - Schematic of Test Fixture



Attachment B - Monotonic Tests

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HILTI HNA TESTING 5666 S 122nd E AVE 74146	SILL PLATE TEST SHEAR (MONOTONIC), AWAY FROM EDGE, 33 MIL	Test Type SHEAR TEST CHEMI	Test # 3-10-1 File Name XYDACCKN Test Date 03/25/10

Setup and installation

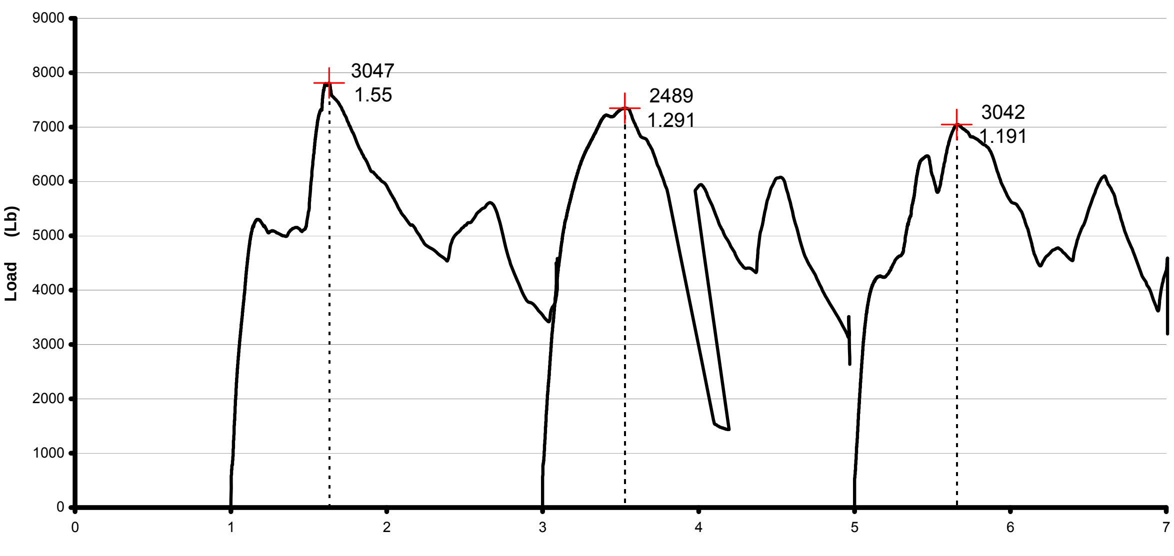
Test Tech	MIKE KELLY				Hole Depth	7	in.
Drill Type	TE-76	Hammer	Yes		Cleaning Method	std	
Drill Bit Type	TE-Y				Cure Time	12 hr	
Bit Before	in.	Bit After	in.	Bit Wear in.	Torque T_{inst}	5-6	ft-lb

Test Equipment

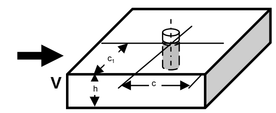
MIC#	002	Load Cell SN	B21342
LVDT SN		521305	
Torque Wrench SN		8008520048	
Load Frame Type		25KT	

Test Parameters

Anchor System	RE 500 SD		Anchor Material	B7	
Lot#			Item#		
Anchor Emb.	7	in.	Anchor Length	8	in.
Anch. Spacing	>= 7.125	in.	Edge Distance	>7	in.
Sample Size	3		Anchor Diameter	5/8	in.
Drill Bit Spec.	MED DRILL BIT				



BASE MATERIAL



Aggregate	Limestone	
Strength	2650.0	psi
Pour Date	3/10/2003	
Last Concret Break	2/2/2010	
Anchor Orientation	Bottom of Block	
Dimensions		

Additional Description and Test Comments:
33 mil 3 5/8" track, 33 ksi, plate washer, washer, and nut

Test Data / Samples		1	2	3	4	5	6	7	8	9	10
Torque	ft-lb	5	6.3	5.7							
Displacement @ Failure	in.	0.631	0.527	1.191							0
Blows To Install	N										
Blows To Expand (HDI)	N										
Turns To Torque	N	0.25	0.25	0.25							
Turns @ 0.5 Torque	N										
Setting Tool Length (HDI)	in.										
Failure Loads	lb	7,811	7,348	7,047							
Failure Mode		TEAR	TEAR	TEAR							
Failure Time	SEC.	104.3	96.4	n/a							
Time Anchor Set											
Time Anchor Pulled											
Test Photo Reference No.											

Test Statistics for Ultimate loads

$\bar{x}$ (lb) =	Sx (lb) =	v (%) =	N =
7,402	385	5.2	3

Failure Mode Index

	Cc = Concrete Cone	Bb = Mortar/Borehole Bond	Sb = Steel (body)	Csp = Concrete Splitting
Po = Anchor Pull Out	Ce = Concrete Edge	Be = Element/Mortar Bond	St = Steel (threads)	Tn = Nut or mating element
Pt = Anchor Pull Through	Cp = Concrete Pryout	Bbe = Mortar/Bond/Borehole	Sn = Steel (form dia.)	Ti = Internal Thread

HILTI HNA TESTING	SILL PLATE TEST	Test Type	Test #	3-10-2
5666 S 122nd E AVE 74146	SHEAR (MONOTONIC), AWAY FROM EDGE, 68 MIL	SHEAR TEST	File Name	XYDACCKN
		CHEMI	Test Date	03/25/10

Setup and installation

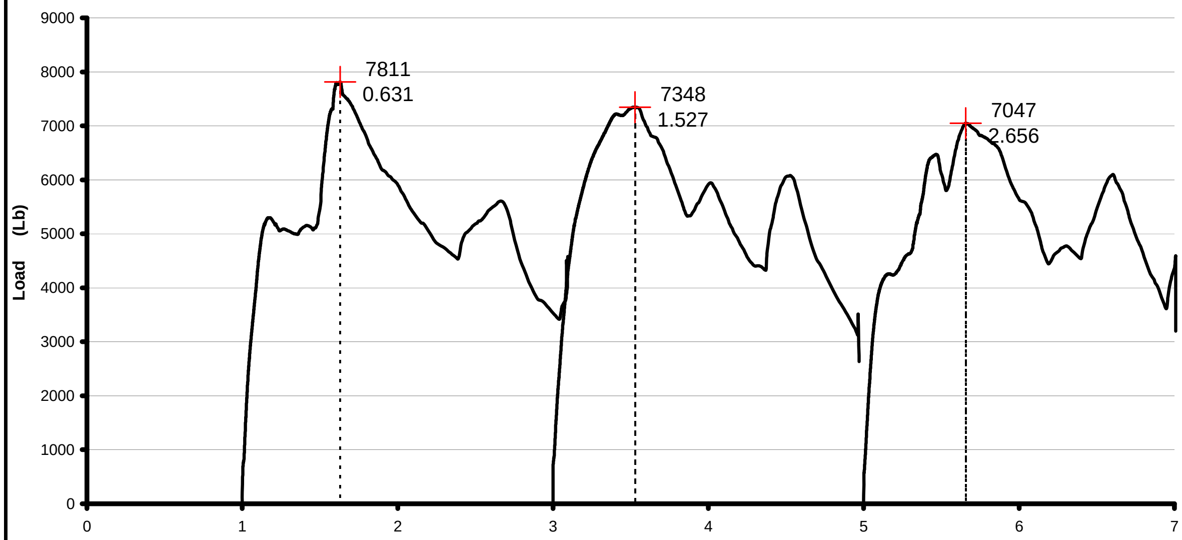
Test Tech	MIKE KELLY				Hole Depth	7	in.
Drill Type	TE 76	Hammer	Yes		Cleaning Method	std	
Drill Bit Type	TE-Y				Cure Time	12 hr	
Bit Before	in.	Bit After	in.	Bit Wear in.	Torque T_{inst}	7-19	ft-lb

Test Equipment

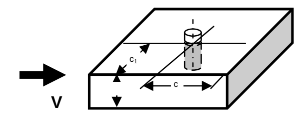
MIC#	002	Load Cell SN	B21342
LVDT SN		521305	
Torque Wrench SN		8008520048	
Load Frame Type		25KT	

Test Parameters

Anchor System	RE 500 SD		Anchor Material	B7	
Lot#			Item#		
Anchor Emb.	7	in.	Anchor Length	8	in.
Anch. Spacing	>7	in.	Edge Distance	>7.125	in.
Sample Size	3		Anchor Diameter	5/8	in.
Drill Bit Spec.	MED DRILL BIT				



BASE MATERIAL



Aggregate	Limestone	
Strength	2650.0	psi
Pour Date	3/10/2003	
Last Concret Break	2/2/10	
Anchor Orientation	Bottom of Block	
Dimensions		

Additional Description and Test Comments:
68 mil 3 5/8" track, 50 ksi, plate washer, washer and nut

Test Data \ Samples		1	2	3	4	5	6	7	8	9	10
Torque	ft-lb	7	19.2	12.5							
Displacement @ Failure	in.	0.631	0.527	0.656							0
Blows To Install	N										
Blows To Expand (HDI)	N										
Turns To Torque	N	0.25	0.25	0.25							
Turns @ 0.5 Torque	N										
Setting Tool Length (HDI)	in.										
Failure Loads	lb	7,811	7,348	7,047							
Failure Mode		TEAR	TEAR	TEAR							
Failure Time	SEC.	104.3	96.4	90.1							
Time Anchor Set											
Time Anchor Pulled											
Test Photo Reference No.											

Test Statistics for Ultimate loads

$\bar{x}$ (lb) =	Sx (lb) =	v (%) =	N =
7,402	385	5.2	3

Failure Mode Index

Po = Anchor Pull Out	Cc = Concrete Cone	Bb = Mortar/Borehole Bond	Sb = Steel (body)	Csp = Concrete Splitting
Pt = Anchor Pull Through	Ce = Concrete Edge	Be = Element/Mortar Bond	St = Steel (threads)	Tn = Nut or mating element
	Cp = Concrete Pryout	Bbe = Mortar/Bond/Borehole	Sn = Steel (form dia.)	Ti = Internal Thread

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HILTI HNA TESTING 5666 S 122nd E AVE 74146	SILL PLATE TEST SHEAR (MONOTONIC), AWAY FROM EDGE, 68 MIL	Test Type SHEAR TEST CHEMI	Test # 03-10-3 File Name XYDACCKD Test Date 03/24/10

Setup and installation

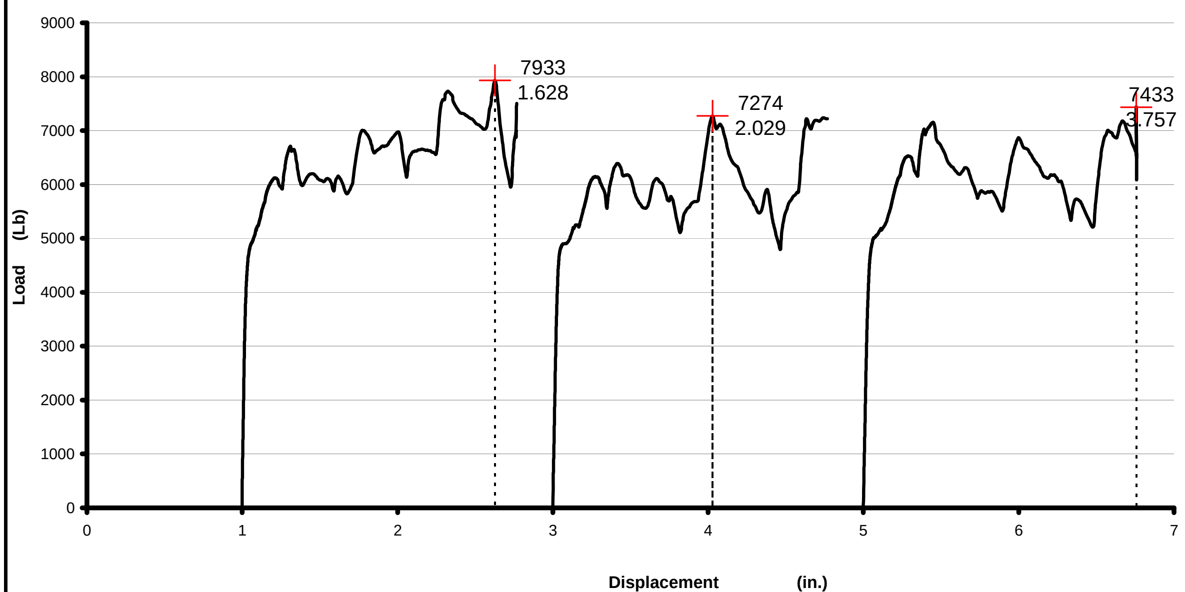
Test Tech	Mike Kelly			Hole Depth	7	in.	
Drill Type	TE 76	Hammer	Yes	Cleaning Method	std		
Drill Bit Type	TE-Y			Cure Time	12 hr		
Bit Before	in.	Bit After in.	Bit Wear in.	Torque T_{inst}	5	ft-lb	

Test Equipment

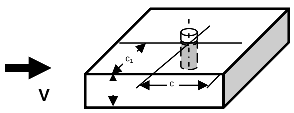
MIC#	002	Load Cell SN	B21342
LVDT SN		521305	
Torque Wrench SN			
Load Frame Type		25KT	

Test Parameters

Anchor System	RE 500 SD		Anchor Material	B7	
Lot#			Item#		
Anchor Emb.	7	in.	Anchor Length	8	in.
Anch. Spacing	>7	in.	Edge Distance	>7.125	in.
Sample Size	3		Anchor Diameter	5/8	in.
Drill Bit Spec.	MED DRILL BIT				



BASE MATERIAL



Aggregate Limestone

Strength 2650.0 psi
Pour Date 3/10/2003
Last Concret Break 2/2/2010
Anchor Orientation Bottom of Block
Dimensions

Additional Description and Test Comments:
68 mil, 3 5/8" track, 50 ksi, plate washer, washer and nut

Test Data / Samples		1	2	3	4	5	6	7	8	9	10
Torque	ft-lb	5	<5	5.2							
Displacement @ Failure	in.	1.628	1.029	1.757							0
Blows To Install	N										
Blows To Expand (HDI)	N										
Turns To Torque	N	0.25	0.25	0.25							
Turns @ 0.5 Torque	N										
Setting Tool Length (HDI)	in.										
Failure Loads	lb	7,933	7,274	7,433							
Failure Mode		TEAR	TEAR	TEAR							
Failure Time	SEC.	91.0	87.1	96.8							
Time Anchor Set											
Time Anchor Pulled											
Test Photo Reference No.											

Test Statistics for Ultimate loads

$\bar{x}$ (lb) =	Sx (lb) =	v (%) =	N =
7,547	344	4.6	3

Failure Mode Index

Po = Anchor Pull Out	Cc = Concrete Cone	Bb = Mortar/Borehole Bond	Sb = Steel (body)	Csp = Concrete Splitting
Pt = Anchor Pull Through	Ce = Concrete Edge	Be = Element/Mortar Bond	St = Steel (threads)	Tn = Nut or mating element
	Cp = Concrete Pryout	Bbe = Mortar/Bond/Borehole	Sn = Steel (form dia.)	Ti = Internal Thread

Hilti. Outperform. Outlast.

HILTI HNA TESTING 5666 S 122nd E AVE 74146	SILL PLATE TEST SHEAR (MONOTONIC), 1 3/4" EDGE, 68 MIL	Test Type SHEAR TEST CHEMI	Test # 3-10-5 File Name XYDACCLN Test Date 03/26/10

Setup and installation

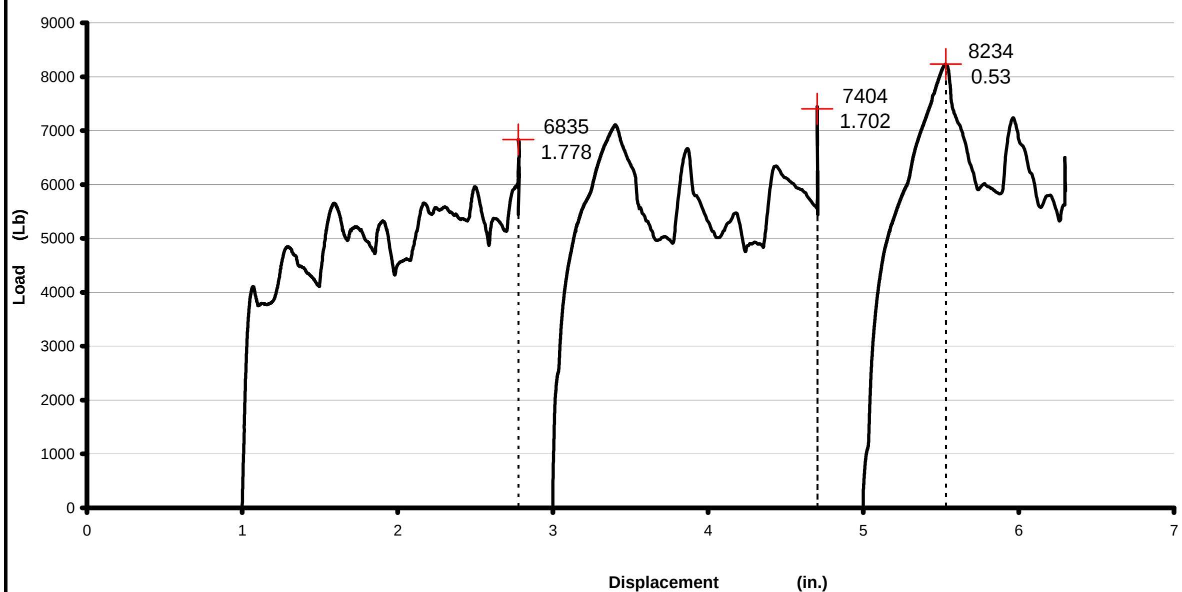
Test Tech Kelly Kummers
Drill Type TE 76 Hammer Yes
Drill Bit Type TE-Y
Bit Before in. Bit After in. Bit Wear in.
Hole Depth 7 in.
Cleaning Method std
Cure Time 12 hr
Torque T_{inst} 5 ft-lb

Test Equipment

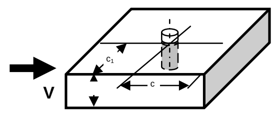
MIC# 002 Load Cell SN B21342
LVDT SN 521305
Torque Wrench SN 8008520048
Load Frame Type 25KT

Test Parameters

Anchor System RE 500 SD Anchor Material B7
Lot# Item#
Anchor Emb. 7 in. Anchor Length 8 in.
Anch. Spacing >7 in. Edge Distance 1 3/4 in.
Sample Size 3 Anchor Diameter 5/8 in.
Drill Bit Spec. MED DRILL BIT



BASE MATERIAL



Aggregate Limestone

Strength 2650.0 psi
Pour Date 3/10/2003
Last Concret Break 2/2/2010
Anchor Orientation Bottom of Block
Dimensions 7 x 9 x 12"

Additional Description and Test Comments:
68 mil, 3 5/8" track, 50 ksi, plate washer, washer and nut

Test Data / Samples		1	2	3	4	5	6	7	8	9	10
Torque	ft-lb	5.2	5.4	<5							
Displacement @ Failure	in.	1.778	1.702	0.53							0
Blows To Install	N										
Blows To Expand (HDI)	N										
Turns To Torque	N	0.25	0.25	0.25							
Turns @ 0.5 Torque	N										
Setting Tool Length (HDI)	in.										
Failure Loads	lb	6,835	7,404	8,234							
Failure Mode		TEAR	TEAR	TEAR							
Failure Time	SEC.	157.3	179.3	168							
Time Anchor Set											
Time Anchor Pulled											
Test Photo Reference No.											

Test Statistics for Ultimate loads

$\bar{x}$ (lb) =	Sx (lb) =	v (%) =	N =
7,491	703	9.4	3

Failure Mode Index

Po = Anchor Pull Out	Cc = Concrete Cone	Bb = Mortar/Borehole Bond	Sb = Steel (body)	Csp = Concrete Splitting
Pt = Anchor Pull Through	Ce = Concrete Edge	Be = Element/Mortar Bond	St = Steel (threads)	Tn = Nut or mating element
	Cp = Concrete Pryout	Bbe = Mortar/Bond/Borehole	Sn = Steel (form dia.)	Ti = Internal Thread

Attachment C - Cyclic Tests

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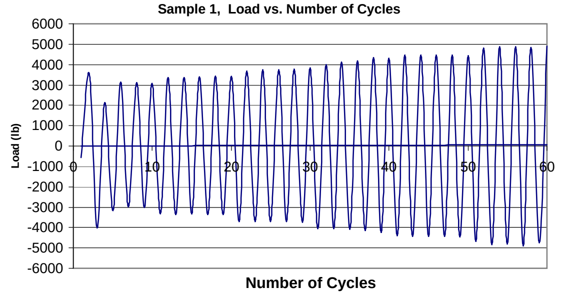
HNA Test Facility | Steel Frame Sill Plate - Cyclic Tests | 4/16/2010

PARAMETERS

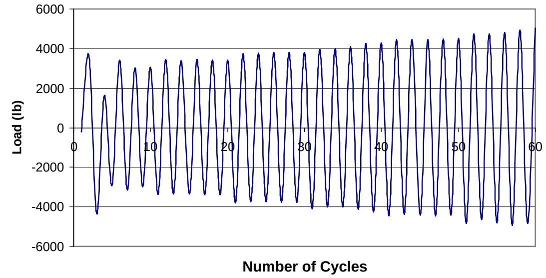
Test Series	4	Min. Yield Strength (50 KSI)	50	Hole size (in)	11/16	Teflon used?	Yes
Track Thick. (mils)	68	Track width (3-5/8 or 6 in.)	3 5/8	n	3	Torque (ft-lb)	5-9
Track Ga.	14	Loading protocol	cyclic	Cyclic frequency (Hz)	0.1	Bolt dia. (in)	5/8 (B7)
Washer type	plate	Edge distance	away	Avg. concrete strgth. (psi)	2,650	Emb Depth (in)	7
5 ea.cyclic loads @ approx. 67, 75, 85, 95, 100, 110% of				4,500 lb		Sampling Rate	1000 Hz

GRAPHS

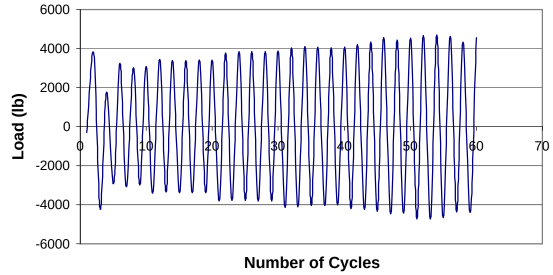
CYCLIC SHEAR - SERIES 4; 68 MIL, AWAY FROM EDGE
Sample 1, Load vs. Number of Cycles



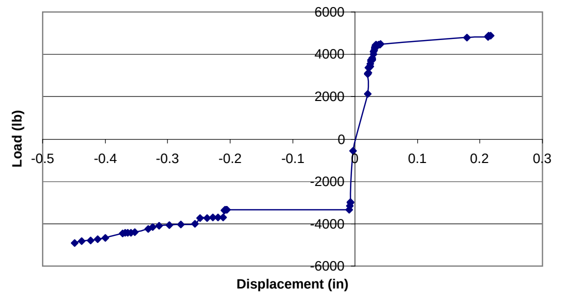
CYCLIC SHEAR - SERIES 4; 68 MIL, AWAY FROM EDGE
Sample 2, Load vs. Number of Cycles



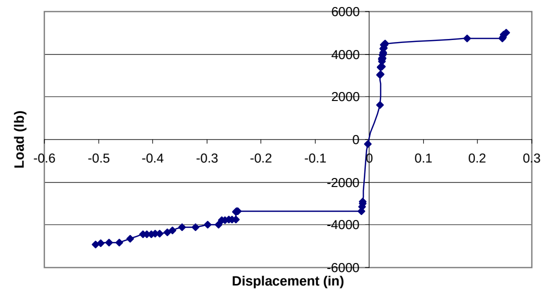
CYCLIC SHEAR - SERIES 4; 68 MIL, AWAY FROM EDGE
Sample 3, Load vs. Number of Cycles



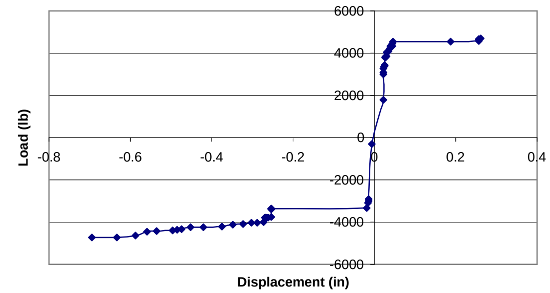
CYCLIC SHEAR - SERIES 4; 68 MIL, AWAY FROM EDGE
Sample 1, Envelope Curve (zero corrected)



CYCLIC SHEAR - SERIES 4; 68 MIL, AWAY FROM EDGE
Sample 2, Envelope Curve (zero corrected)



CYCLIC SHEAR - SERIES 4; 68 MIL, AWAY FROM EDGE
Sample 3, Envelope Curve (zero corrected)



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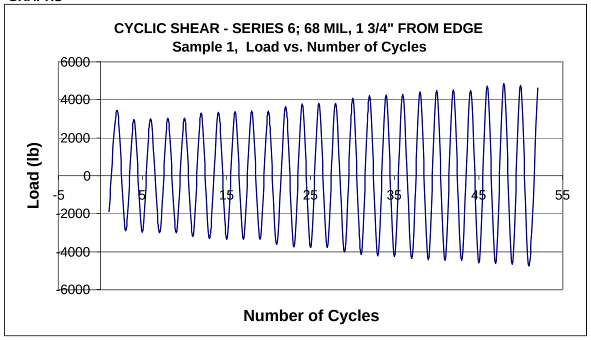
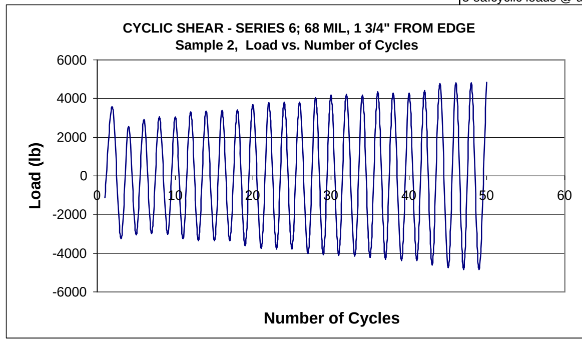
HNA Test Facility | **Steel Frame Sill Plate - Cyclic Tests** | **4/16/2010**

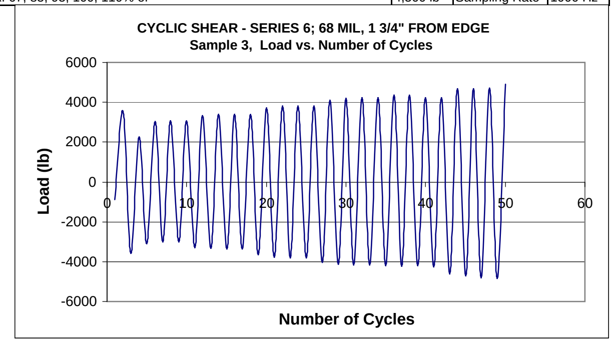
PARAMETERS

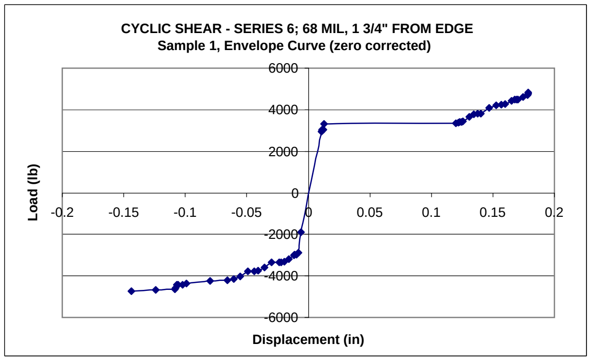
Test Series	6	Min. Yield Strength (50 KSI)	50	Hole size (in)	11/16	Teflon used?	Yes
Track Thick. (mils)	68	Track width (3-5/8 or 6 in.)	3 5/8	n	3	Torque (ft-lb)	5-9
Track Ga.	14	Loading protocol	cyclic	Cyclic frequency (Hz)	0.1	Bolt dia. (in)	5/8
Washer type	plate	Edge distance	1 3/4	Avg. concrete strgth. (psi)	2,650	Emb Depth (in)	7
5 ea.cyclic loads @ approx. 67, 85, 95, 100, 110% of					4,500 lb	Sampling Rate	1000 Hz

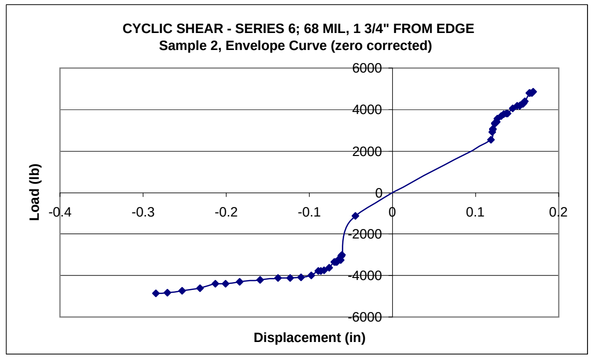
GRAPHS

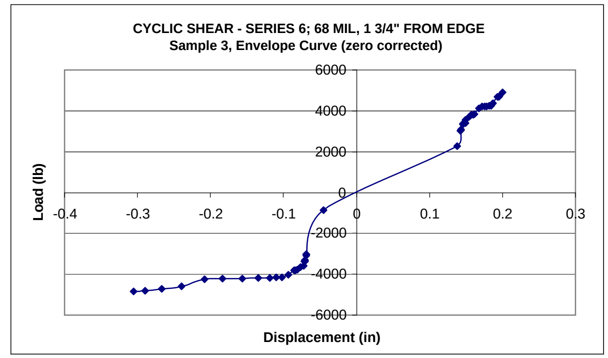












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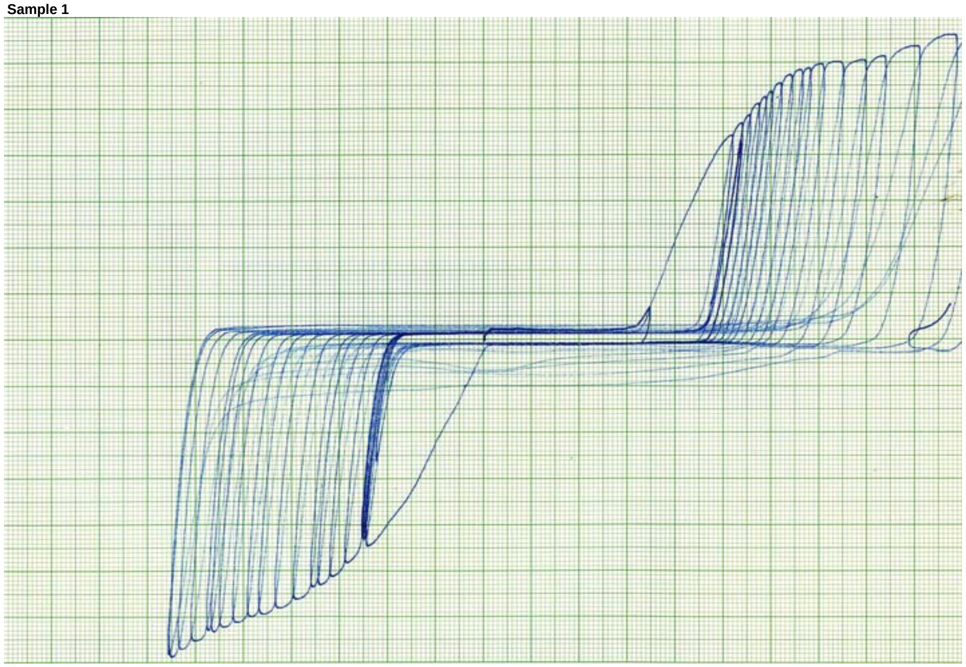
HNA Test Facility | **Steel Frame Sill Plate - Cyclic Tests** | **5/14/2010**

PARAMETERS

Test Series	6	Min. Yield Strength (50 KSI)	50	Hole size (in)	11/16	Teflon used?	Yes
Track Thick. (mils)	68	Track width (3-5/8 or 6 in.)	3 5/8	n	3	Torque (ft-lb)	5-9
Track Ga.	14	Loading protocol	cyclic	Cyclic frequency (Hz)	0.1	Bolt dia. (in)	5/8
Washer type	plate	Edge distance	1 3/4	Avg. concrete strgth. (psi)	2,650	Emb Depth (in)	7
5 ea.cyclic loads @ approx. 67, 85, 95, 100, 110% of					4,500 lb	Sampling Rate	1000 Hz

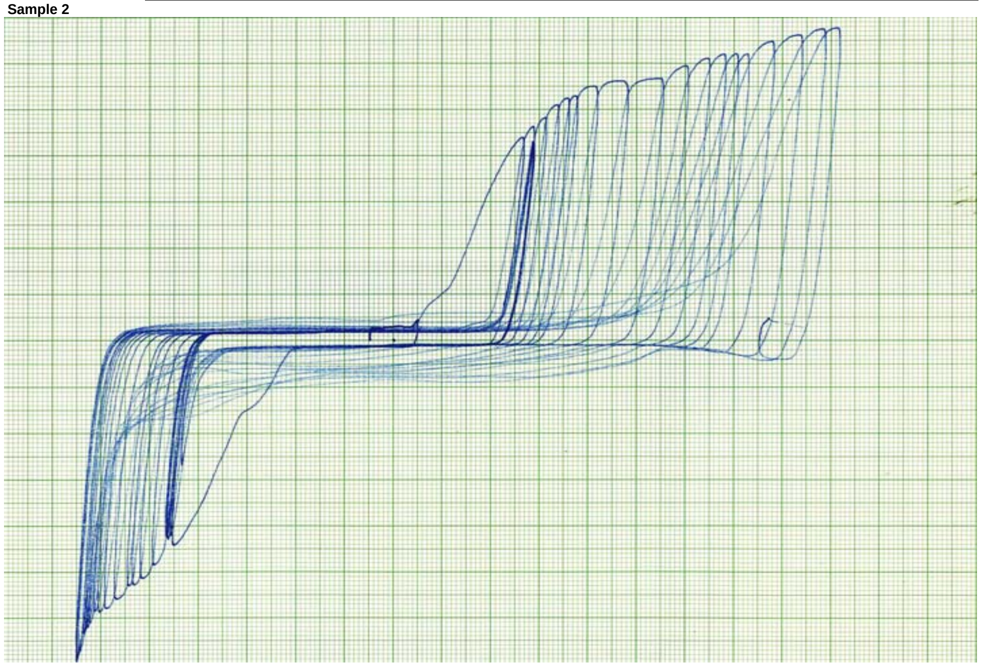
GRAPHS

Sample 1

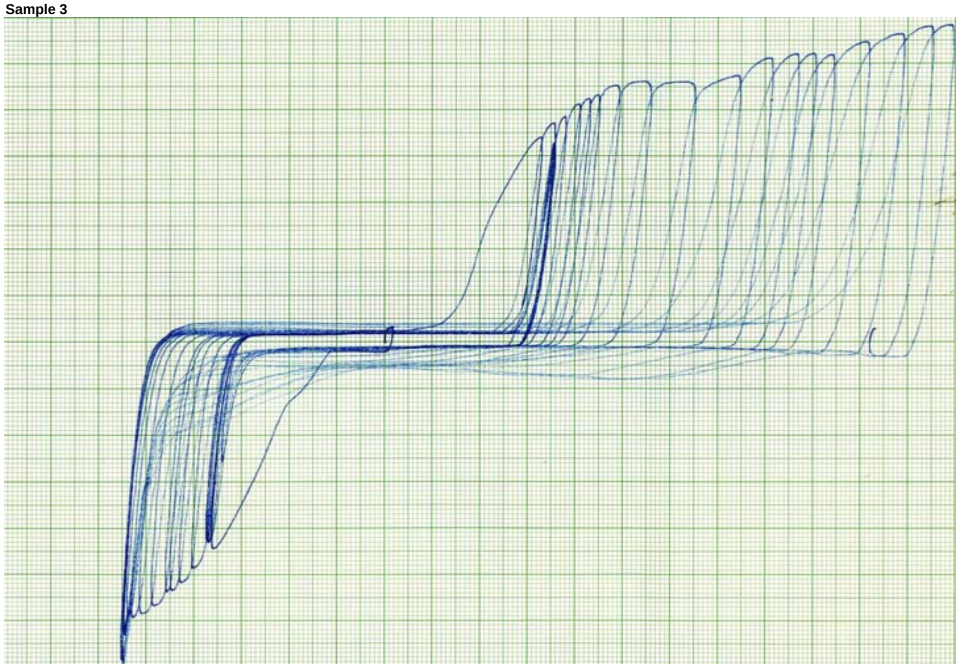


Last two curves cut off! ←

Sample 2



Sample 3



X axis - 1cm = 0.025"; Y axis - 1cm = 817 lbs.

HNA Test Facility | Steel Frame Sill Plate - Cyclic Tests | 4/16/2010

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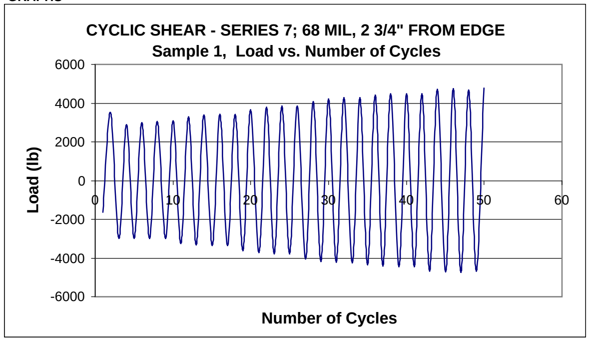
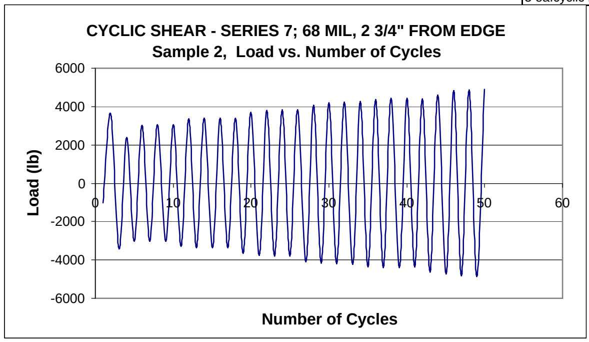
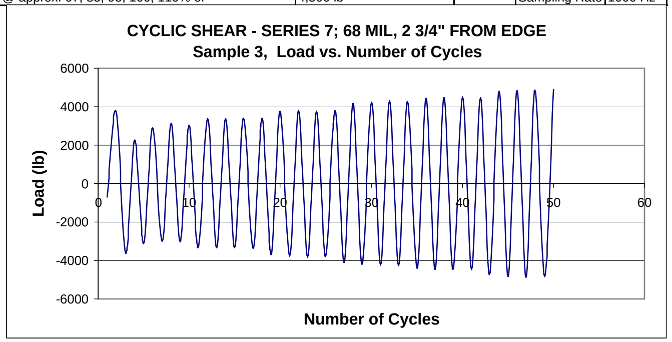
PARAMETERS

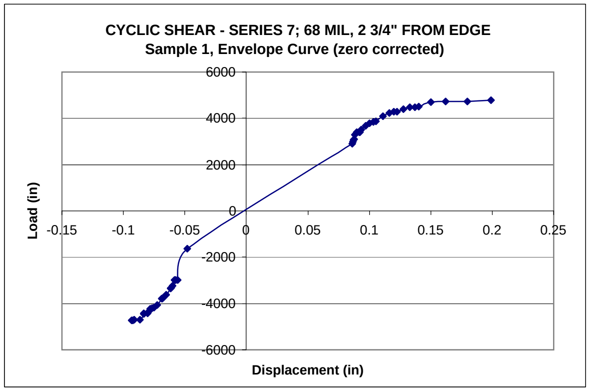
Test Series	7	Min. Yield Strength (50 KSI)	50	Hole size (in)	11/16	Teflon used?	Yes
Track Thick. (mils)	68	Track width (3-5/8 or 6 in.)	6	n	3	Torque (ft-lb)	5-9
Track Ga.	14	Loading protocol	cyclic	Cyclic frequency (Hz)	0.1	Bolt dia. (in)	5/8
Washer type	plate	Edge distance	2 3/4"	Avg. concrete strgth. (psi)	2,500	Emb Depth (in)	7
5 ea.cyclic loads @ approx. 67, 85, 95, 100, 110% of				4,500 lb		Sampling Rate	1000 Hz

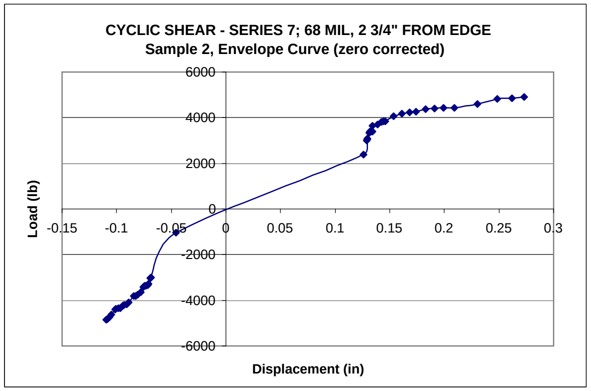
GRAPHS

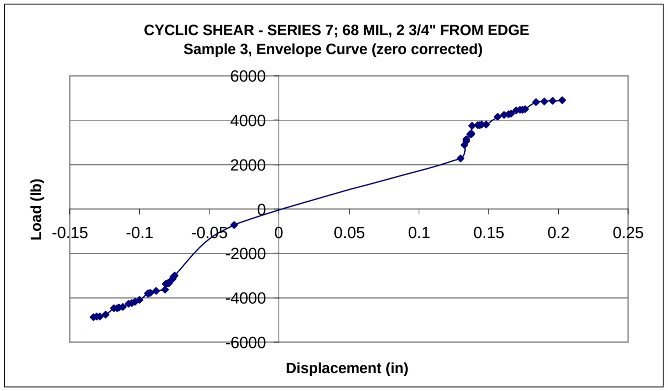












Attachment D – Material Property Tests

STANDARD TESTING AND ENGINEERING COMPANY

Standard Testing - Tulsa Office
10816 E. Newton St., Suite 110
Tulsa, OK 74116 (918) 439-9539

Area Offices

902 Trails West Loop	Enid, OK 73703	(580) 237-3130
202 SE J Avenue	Lawton, OK 73501	(580) 353-0872
3400 N. Lincoln Blvd.	Oklahoma City, OK 73105	(405) 528-0541

Acct ID: 2120HIL20 File No: 2120-0024
Report Date: 02/04/2010
Project: Drill Bit and Anchor Testing
Location: 7x9 Blocks, AE #13-103
Client: Hilti, Inc.

Date Sampled: 03/10/2003
Sampled By: Stuart Batchelor
By Order Of: John w/ AE
Order Number:
Number of Specimens: 14

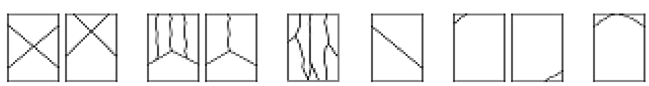
REPORT: Concrete Compression

LAB NO: 37707
Test Method: See Below

TEST RESULTS

Report No: 37707

Spec Nbr	Age Tested (days)	Diameter (in)	Area (in²)	Maximum Load (lbs)	Break Type	Cure	Compressive Strength (PSI)	Average Strength (PSI)	Comments
1	18	6.00	28.274	51,416	Type 1	Fld	1,820		Test Date - 3/28/03
2	18	6.00	28.274	57,763	Type 1	Fld	2,040	1,930	Test Date - 3/28/03
3	28	6.00	28.274	64,685	Type 1	Fld	2,290		Test Date - 4/7/03
4	28	6.00	28.274	68,007	Type 1	Fld	2,410	2,350	Test Date - 4/7/03
5	90	6.00	28.274	70,855	Type 1	Fld	2,510		Test Date - 6/8/03
6	90	6.00	28.274	69,728	Type 1	Fld	2,470		Test Date - 6/8/03
7	90	6.00	28.274	75,344	Type 1	Fld	2,660	2,550	Test Date - 6/8/03
8	2,521	6.00	28.274	72,290	Type 6	Fld	2,560		Test Date - 2/2/10
9	2,521	6.00	28.274	74,760	Type 2	Fld	2,640		Test Date - 2/2/10
10	2,521	6.00	28.274	77,420	Type 5	Fld	2,740	2,650	Test Date - 2/2/10
11									
12									
13									
14									



Type 1 Type 2 Type 3 Type 4 Type 5 Type 6

Orig: Hilti, Inc. (Tulsa, OK) Attn: Andrew Shouse
(1-ec copy)
1-ec Allan Edwards Attn: Jamee Hamilton
1-cc Laboratory

Respectfully Submitted,
Standard Testing and Engineering Company

Terri Sullivan
Tulsa Operations Manager

STANDARD TESTING AND ENGINEERING COMPANY

902 Trails West Loop
202 SE J Avenue
3400 N. Lincoln Blvd.

Standard Testing - Tulsa Office
10816 E. Newton St., Suite 110
Tulsa, OK 74116 (918) 439-9539

Area Offices

Enid, OK 73703	(580) 237-3130
Lawton, OK 73501	(580) 353-0872
Oklahoma City, OK 73105	(405) 528-0541

Acct ID: 2120HIL20 File No: 2120-0024
Report Date: 02/04/2010
Project: Drill Bit and Anchor Testing
Location: 7x9 Blocks, AE #13-103
Client: Hilti, Inc.

Date Sampled: 03/10/2003
Sampled By: Stuart Batchelor
By Order Of: John w/ AE
Order Number:
Number of Specimens: 14

REPORT: Concrete Compression

LAB NO: 37707
Test Method: See Below

TEST RESULTS

Report No: 37707

Curing Method: Field
Time Sampled: 1:25 pm
Temp.: Ambient: 61ºF
Mix: 45ºF
Slump: 2.5 Inches
Air Content: 1.8%

Transported By: STEC
Source/Sampled At: Allen Edwards/Truck
Plant: at plant
Truck No:
Mix Code:
Ticket No:

Quantity Represented:
Remarks:
Test Method (As Applicable): ASTM C31, C39, C138, C143, C172, C231, C1064, C1231; AASHTO T22, T23, T119, T121, T141, T152, T309

Orig: Hilti, Inc. (Tulsa, OK) Attn: Andrew Shouse
(1-ec copy)
1-ec Allan Edwards Attn: Jamee Hamilton
1-cc Laboratory

Respectfully Submitted,
Standard Testing and Engineering Company

Terri Sullivan
Tulsa Operations Manager

Sherry Laboratories
3100 North Hemlock Circle
Broken Arrow, OK 74012-1115

Tel: 918-258-6066
800-982-8378
Fax: 918-258-1154

LABORATORY REPORT

Attn: Kelly Kummers
HILTI, INC.
5666 South 122 East Ave.
TULSA, OK 74146

Report No.: **10050039-001-v1**
Date Received: **5/3/2010**
Date Reported: **5/6/2010**
P.O. No.: **Verbal**

Sample Description: (1) 3-5/8" Wide (Narrow) x 18" Long x 0.035" Thick Sill Plate Tracks Test Sample, 33 mil

Tensile Test (Rectangular) per ASTM E8-08

Parameter	Result
Orientation	Parallel to Length of the Specimen
Thickness, inch	0.034
Width, inch	0.505
Tensile Strength, psi	52,000
Yield Strength, psi at 0.2% offset	32,600
Elongation in 2 inch, %	41

Approved by: ______________________
Jeffrey Simmons, Laboratory Director
Sherry Laboratories

Sherry Laboratories
3100 North Hemlock Circle
Broken Arrow, OK 74012-1115

Tel: 918-258-6066
800-982-8378
Fax: 918-258-1154

LABORATORY REPORT

Attn: Kelly Kummers
HILTI, INC.
5666 South 122 East Ave.
TULSA, OK 74146

Report No.: **10050039-002-v1**
Date Received: **5/3/2010**
Date Reported: **5/6/2010**
P.O. No.: **Verbal**

Sample Description: (1) 3-5/8" Wide (Narrow) x 18" Long x 0.071" Thick Sill Plate Tracks Test Sample, 68 mil

Tensile Test (Rectangular) per ASTM E8-08

Parameter	Result
Orientation	Parallel to Length of the Specimen
Thickness, inch	0.071
Width, inch	0.505
Tensile Strength, psi	55,500
Yield Strength, psi at 0.2% offset	52,500
Elongation in 2 inch, %	28

Approved by: ______________________
Jeffrey Simmons, Laboratory Director
Sherry Laboratories

Sherry Laboratories
3100 North Hemlock Circle
Broken Arrow, OK 74012-1115

Tel: 918-258-6066
800-982-8378
Fax: 918-258-1154

LABORATORY REPORT

Attn: Kelly Kummers
HILTI, INC.
5666 South 122 East Ave.
TULSA, OK 74146

Report No.: 10050039-003-v1
Date Received: 5/3/2010
Date Reported: 5/6/2010
P.O. No.: Verbal

Sample Description: (1) 6" (Wide) x 18" Long x 0.071" Thick Sill Plate Tracks Test Sample, 68 mil

Tensile Test (Rectangular) per ASTM E8-08

Parameter	Result
Orientation	Parallel to Length of the Specimen
Thickness, inch	0.070
Width, inch	0.504
Tensile Strength, psi	55,500
Yield Strength, psi at 0.2% offset	53,000
Elongation in 2 inch, %	23

Approved by: ______________________
Jeffrey Simmons, Laboratory Director
Sherry Laboratories

American Iron and Steel Institute

1140 Connecticut Avenue, NW
Suite 705
Washington, DC 20036

www.steel.org

Steel Framing Alliance

Steel. The Better Builder.

1140 Connecticut Avenue, NW
Suite 705
Washington, DC 20036

www.steelframing.org

Research Report RP-10-3

The New Steel