CFS-NEES

Advancing Cold-Formed Steel Earthquake Engineering

RESEARCH REPORT

Test Report on Cold-Formed Steel Shear Walls

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CFS-NEES – RR03
June 2012

This report was prepared as part of the U.S. National Science Foundation sponsored CFS-NEES project: NSF-CMMI-1041578: NEESR-CR: Enabling Performance-Based Seismic Design of Multi-Story Cold-Formed Steel Structures. The project also received supplementary support and funding from the American Iron and Steel Institute. Project updates are available at www.ce.jhu.edu/cfsnees. Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the National Science Foundation, nor the American Iron and Steel Institute.

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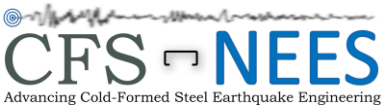

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SUMMARY

The objective of report is to detail recent cyclic tests on cold-formed steel (CFS) framed shear walls sheathed with Oriented Strand Board (OSB). The tests details are motivated from shear walls designed for a two-story ledger-framed building that will undergo full-scale shake table testing as part of the National Science Foundation funded Network for Earthquake Engineering Simulation (NEES) project: CFS-NEES (www.ce.jhu.edu/bschafer/cfsnees). Monotonic and cyclic (CUREE protocol) tests are conducted on 4 ft × 9 ft (1.22m × 2.74 m) and 8 ft × 9 ft (2.44m ×2.74 m) shear walls utilizing 54 mil (1.37mm) back-to-back chord studs and 7/16 in. (11.1 mm) OSB sheathing on the exterior. Practical building details studied in the shear wall tests include the impact of (a) ledger track, which is attached to the top of the interior face of the wall, (b) gypsum, which is attached to the interior face of the wall below the ledger track, (c) locations of panel seams, both horizontal and vertical in the OSB, and (d) the impact of differing stud thickness and grade for the field studs. The information will be used to assess current design procedures utilizing AISI-S213-07 and to develop nonlinear (hysteretic) models of the shear walls in the CFS-NEES model building so that full building system performance can be assessed.

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1 Background and Objectives

The most common seismic lateral force resisting system for light steel framing is wood sheathed, cold-formed steel framed, shear walls. A wide body of testing has been conducted on these walls as embodied in the AISI-S213-07 standard. The shear walls designed for a two-story ledger-framed building that will undergo full-scale shake table testing as part of the National Science Foundation funded Network for Earthquake Engineering Simulation (NEES) project: CFS-NEES (www.ce.jhu.edu/bschafer/cfsnees) were also designed to AISI-S213-07. However, in actual buildings additional details beyond the scope of AISI-S213-07 emerge, including: (a) the presence of a substantial ledger (track) on the interior face of the shear walls, (b) shear wall sizes that don't match panel sizes and thus the presence of both vertical and horizontal panel seams in the walls, (c) the presence of interior gypsum board, and (d) use of field studs that do not match the grade or thickness of the chord studs. Further, while AISI-S213-07 provides strength it provides no insight on the hysteretic performance of the shear walls. In order to explore the expected performance-basis of shear walls in the CFS-NEES building tests were conducted to understand the impact of practical details and to provide the necessary information for subsequent hysteretic characterization of the shear walls.

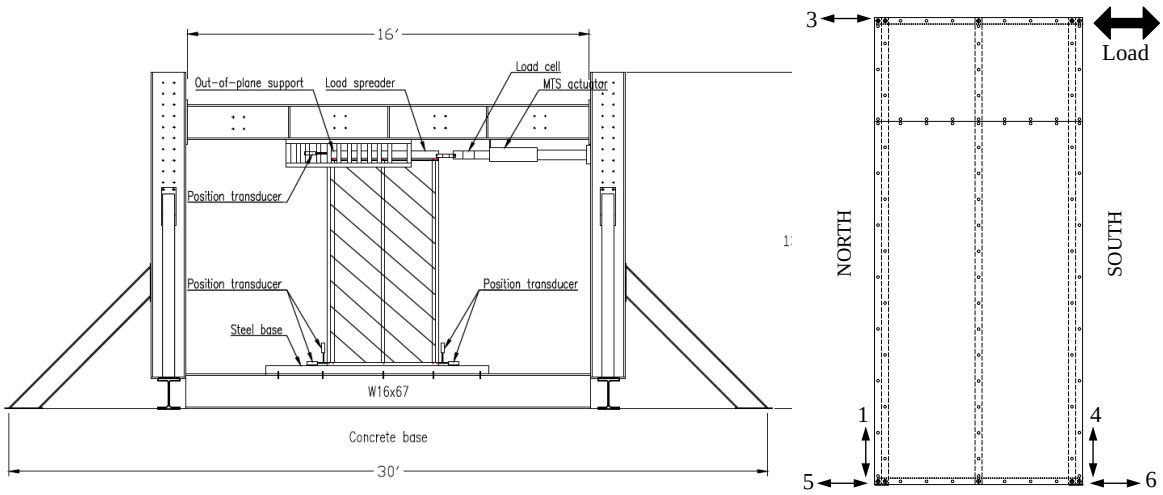
2 Test Program

The test program was carried out from October 2010 to December 2011 at University of North Texas, Denton, Texas.

2.1 Test Setup

Both monotonic and cyclic tests were performed on a 16ft wide and 12ft high adaptable structural steel testing frame. Figure 1 depicts the test frame. Shear walls were bolted to a steel base beam consisting of a 10in.×5in.× ½ in. structural steel tube. The tube was attached to a W16×67 beam, which was bolted to the concrete floor slab with ¾ in. anchor bolts at 24 in. on center. The tube has cut-outs along the length to provide access to the anchor bolts that connect the tube with the bottom of the shear wall track. On the top of the rig, a structural WT is used to transfer the lateral force from the actuator to the shear wall. The WT flanges connected to the top of shear wall with two lines of No.10 (1½in.) hex head (with washers) self-drilling screws at every 3 in. along the top track. Out-of-plane support for the WT outstand is provided by a steel tube and rollers to restrict the shear wall to in-plane movement. The WT and roller details are shown in Figure 3.A gap of approximately 1/8 in. was provided between the WT shape and the steel rollers to avoid significant friction during the test. For the monotonic and cyclic tests the shear anchors use an ASTM A325 5/8 in. diameter with standard cut washers (ASME B18.22.1(1998)) and the hold-down is a Simpson Strong-Tie® S/HDU6 with 5/8 in. diameter ASTM A325 bolts.

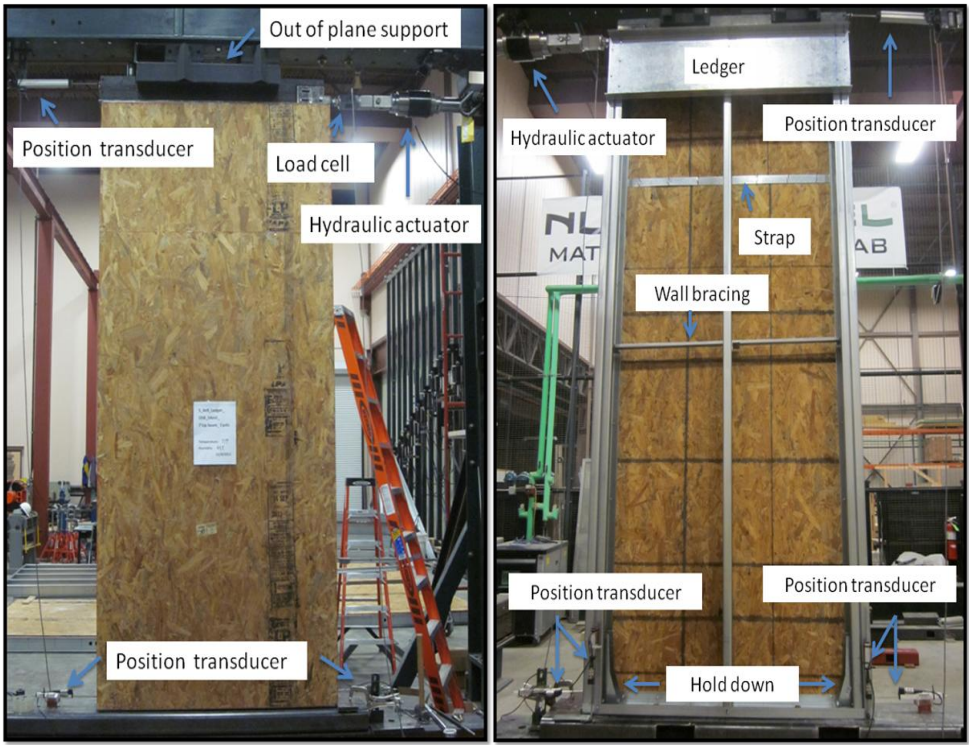
All of the shear walls were assembled on the ground in the laboratory. For monotonic test 1c and 11c the OSB was installed on the specimens vertically. A steel clamp was used to adjust the OSB position on the stud to track frame in that case. The bottom 1/8 in. of the OSB was shaved off to avoid touching the steel base beam during the testing.



(a) (b)

(c)

Figure 1 Shear wall test set up (a) schematic of testing rig with specimen, (b) sensor plan where numbers correspond to position transducers measuring along the direction indicated by the arrows, (c) test frame



(a) front view (b) back view

Figure 2 Test setup and specimen details

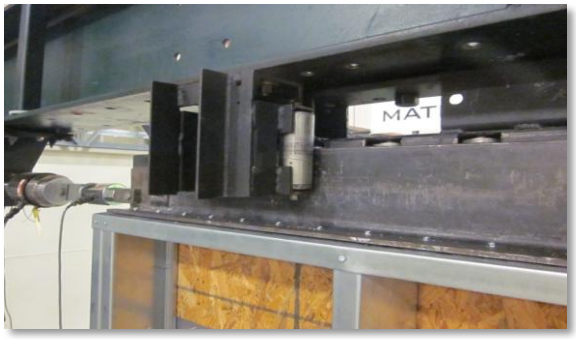


Figure 3 Close-up of out-of-plane support and WT shape

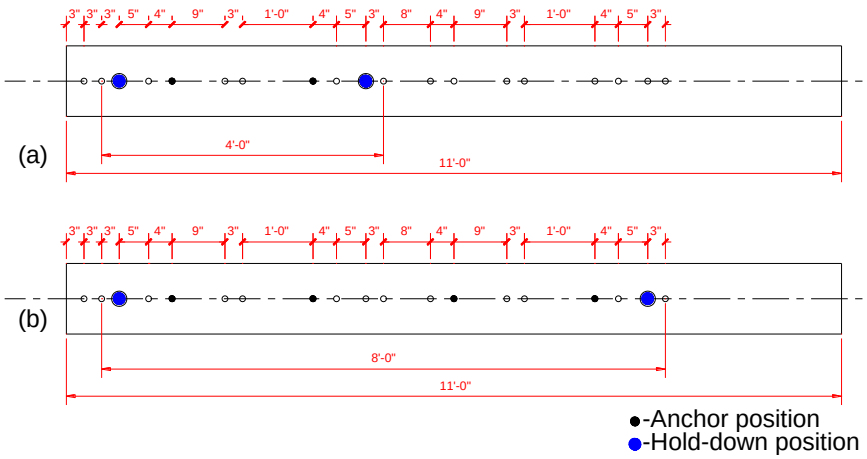


Figure 4 Anchor placements along frame base (top view) for (a) 4 ft and (b) 8 ft wide wall. (Large (blue) dots indicate hold down position and small black dots represent anchor position.)

The testing frame was equipped with one MTS® 35 kip hydraulic actuator with ± 5 in. stroke. A MTS®407 controller and 20-GPM MTS® hydraulic power unit were employed to support the loading system. A 20-kip TRANSDUCER TECHNIQUES®SWO universal load cell was placed in a pin connection between the actuator rod and the WT shape connected to the shear wall top track. Five NOVOTECHNIC® position transducers were used to measure the horizontal displacement at the top of wall, and the vertical and horizontal displacements of the bottom of the two boundary studs. The data acquisition system consisted of a National Instruments® unit (including a PCI6225 DAQ card, a SCXI1100 chassis with SCXI1520 load cell sensor module and SCXI1540 LVDT input module) and a desktop PC. The applied force and the five displacements were measured and recorded continuously during the test.

2.2 Test Procedure

The Monotonic and cyclic test were conducted in displacement control. The monotonic tests were in accordance with ASTM E564(Standard Practice for Static Load Test for Shear Resistance of Framed Walls Buildings) A preload of approximately 10% of the estimated ultimate load was applied to shear wall before testing and held for 5 minutes to seat all connections. Approximately

one third of the estimated ultimate load was applied then removed and all forces and deformations recorded to document the recovery of the wall. Reload and unload occurred in increments of approximately 1/3 the estimated ultimate load until failure occurred.

The CUREE protocol was chosen for all of the cyclic tests. The CUREE basic loading history is shown in the Figure 5. It includes 43 cycles with displacement amplitudes that are based on a percentage of ultimate displacement from the monotonic test. If the panel has not failed after 40cycles, additional cycles are added. Each subsequent phase consists of a primary cycle with an increase of 50% over the previous primary cycle, followed by two trailing cycles with amplitude of 75% of the primary one. Table 1 CUREE loading history lists the details of each phase in the CUREE protocol. Both the 4ftx9ft and 8ftx9ft shear walls used 43 cycles (except test 3 which is 40 cycles). The CUREE protocol is in accordance with the test method C ASTM E2126(2007).

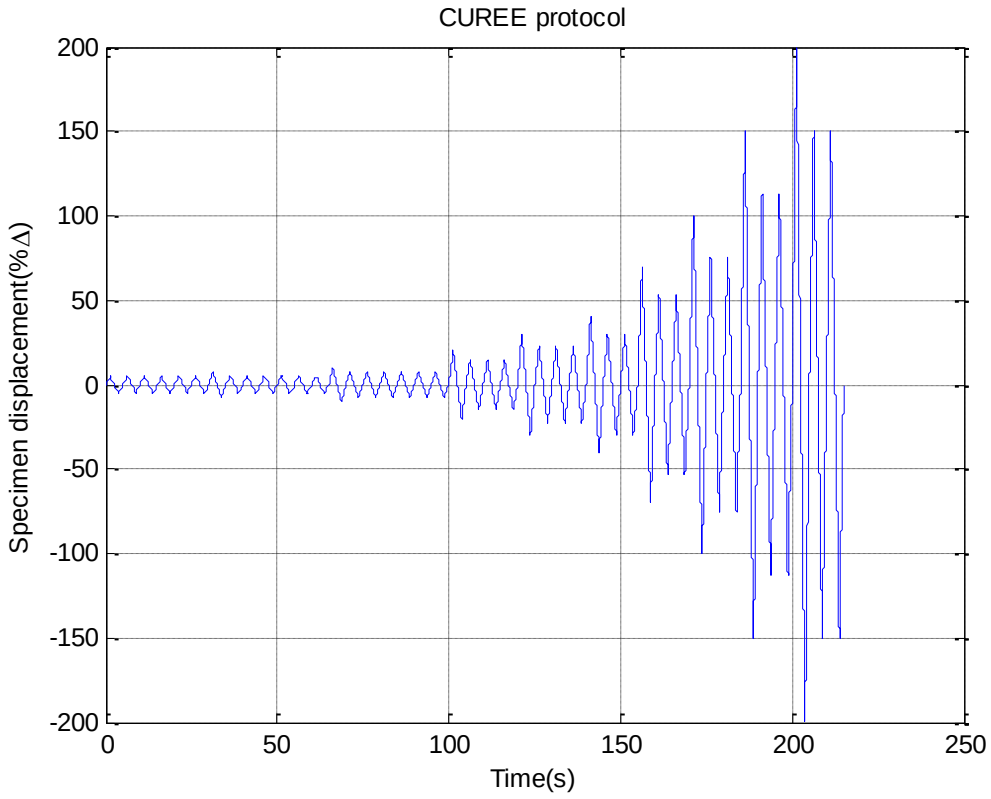


Figure 5 CUREE loading history as realized in a test

Table 1 CUREE loading history

Cyclic No.	Δ%	Cyclic No.	Δ%
1	5	21	20
2	5	22	15
3	5	23	15
4	5	24	15
5	5	25	30
6	5	26	23
7	7.5	27	23
8	5.6	28	23
9	5.6	29	40
10	5.6	30	30
11	5.6	31	30
12	5.6	32	70
13	5.6	33	53
14	10	34	53
15	7.5	35	100
16	7.5	36	75
17	7.5	37	75
18	7.5	38	150
19	7.5	39	113
20	7.5	40	113
		41	200
		42	150
		43	150

Note: Δ-Percentage of current displacement amplitude
and ultimate displacement from the monotonic test.

2.3 Test Specimens

Overview

As illustrated in Figure 6, the baseline specimen consisted of either 4 ft x 9 ft or 8 ft x 9 ft walls framed with 600S162-54(50ksi) studs spaced 24 in. o.c. and connected with No. 10 flathead screws to 600T150-54 (50ksi) track (member nomenclature per AISI-S200-07). Studs were spaced at 24 in. o.c. and braced with CRC as detailed in Figure 5a. Chord studs consisted of back-to-back studs assembled with pairs of No. 10 flathead screws spaced every 12 in..Simpson Strong-Tie S/HDU6hold downs were attached on the inward face at the bottom of the chord studs. Twelve No.14 fasteners attached the hold downs to the chord studs.

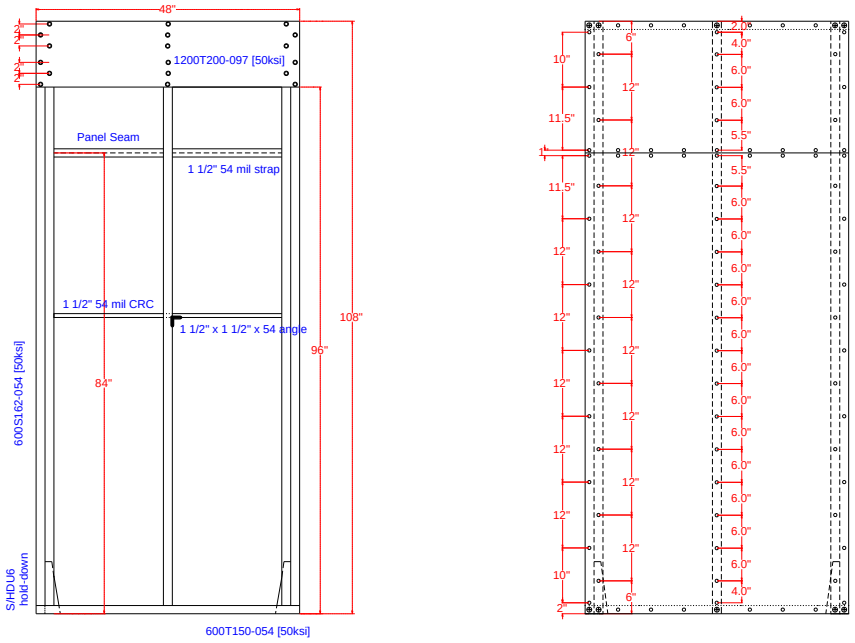
In most cases (see Table 2 Test matrix) 7/16 in. OSB was attached with No. 8 flat head fasteners (1-15/16 in. long) at 6 in. o.c. to the stud and track. When seams of the OSB do not fall on a stud, taught 1 ½ in. wide 54 mil strap was used as shown in Figure 4a. When the rim track/ledger is present (again see Table 2) a 1200T200-097 (50ksi) track is attached with No. 10 fasteners to the top 12 in. of the interior face of the wall. When gypsum board is present 5/8 in. gypsum board is attached with No. 6 fasteners at 6 in. o.c. to the lower 8 ft. (below the ledger).

Connection of the shear wall to the testing rig is accomplished in the top track by dragging in the applied shear through two lines of No. 10 fasteners spaced 3 in. o.c. (labeled load spreader). The bottom track is connected to the steel base (Figure 4) by 5/8 in. diameter A325 bolts at the hold down locations and directly through the track every 2 ft. along the wall with the same bolts.

Table 2 Test matrix

Test	**Wall Size**	**Load Type**	**F. Sheathing**	**B. Sheathing**	**Stud**	**Ledger**	**H. Seam**	**V. Seam**	**Peak Load**	**Peak Disp.**
quantity		*mono/cyclic*	*OSB*	*Gypsum*	*600S162-xx*	*1200T200-97*			P_{ave}	Δ_{ave}
unit	ftxft	–	✔/-	✔/-	1/1000 in.	✔/-	ft	ft	plf	in
1c	4x9	Monotonic	✔	–	54	✔	8’up	-	1225	2.96
2	4x9	Cyclic	✔	–	54	✔	8’up	-	1102	2.82
3	4x9	Cyclic	✔	✔	54	✔	8’up	-	1111	2.67
4	4x9	Cyclic	✔	–	54	–	8’up	-	1004	2.40
5	4x9	Cyclic	✔	–	54	✔	7’up	-	987	2.39
6	4x9	Cyclic	✔	–	54	–	7’up	-	1031	2.24
7*	4x9	Cyclic	✔	–	54	–	8’up	1’over	897	2.23
8*	4x9	Cyclic	✔	–	54	–	8’up	2’over	982	3.33
9	4x9	Cyclic	✔	–	54	–	8’up	2’over	906	3.56
10	4x9	Cyclic	✔	–	54	–	4.5’up	2' over	950	2.94
11c	8x9	Monotonic	✔	–	54	✔	8’up	-	1089	2.42
12	8x9	Cyclic	✔	–	54	✔	8’up	-	1156	1.96
13	8x9	Cyclic	✔	✔	54	✔	8’up	-	1232	1.91
14	8x9	Cyclic	✔	–	54	–	8’up	-	1023	1.94
15	8x9	Cyclic	✔	–	33	–	8’up	-	861	1.64
16	8x9	Cyclic	–	✔	54	✔	8’up	-	231	1.47

Notes: CUREE protocol employed for cyclic testing, *additional field stud 1' over from side



(a) front view (b) back view

Figure 6 Shear wall specimen drawing (details are the same for 8 ft wide shear walls)

Details

The details of the components of the test are given as follows:

Studs:

600S162-54 structural studs, 0.0570in. thick, basic dimensions 6 in.depth ×1-5/8 in. flange width, 50 ksi steel, standard punch-out in the middle. For test 15 only field studs utilize 600S162-33 structural studs, 0.0365in. thick, basic dimensions 6 in.depth ×1-5/8 in. flange width, 33 ksi steel, standard punch-out in the middle.

Tracks:

600T150-54 (50 ksi) structural track

Ledger:

1200T200-97 (50 ksi) structural track. Typical installation details shown in Figure 7.

(a) Ledger attached to top of shear wall

(b) screws in middle

(c) screws at the end (staggered)

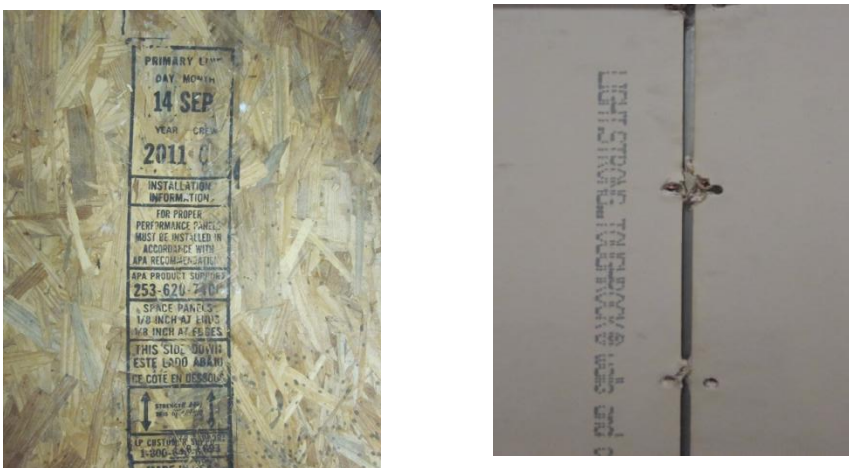
Figure 7 Ledger framed to shear wall

Strap:

The strap placed on the horizontal seam location under the OSB is 1.5in. wide with a thickness of 54mil. Strap length is the same as the width of the shear wall. The strap was connected with No. 8 (1-15/16 in. long) every 6 in. along the length to transfer shear force on the seam.

Sheathing:

The OSB sheathing is 7/16 in., 24/16 rated, exposure 1. Figure 8 shows the panel marking on the OSB and Gypsum board. The gypsum board is 4 ft x 8 ft with ½ in. thickness. The oriented strand board and gypsum board were both purchased at Lowe's store at Denton, Texas.



(a) OSB (b) gypsum board

Figure 8 Sheathing used in tests

Wall bracing:

Wall bracing consists of a cold rolled steel channel and a clip angle. The clip was attached to the stud at the middle of the punch-out with two No. 8 screws. The channel bridged the punch-out and was connected tot the clip with a No.8 screw. Figure 9 shows the wall bracing connection with field stud. The dimensions of the steel clips are 1½ in.×1½ in.×0.054 in., and 5 in. long. The cold-rolled channel is 1½ in.×0.054 in. and the length is in the same as the width of the shear wall.

Figure 9 Wall bracing detail

Hold-downs:

Simpson StrongTie® S/HDU6 hold-down with 14 No. 14 (1 in.) HWT Self-Drilling screws were installed. A 5/8 in. diameter ASTM 325 2.5in. long anchor bolt was used to connect to the steel base. The details are shown in Figure 10. Also, as shown in Figure 10, the hold down deforms during the test.

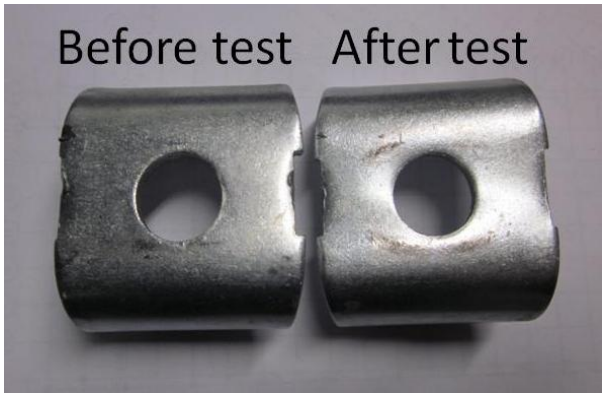


Figure 10 Deformation of hold-down (view from bottom, test 12 shown)

Screws and Screwdriver:

Simpson StrongTie® Quick Drive PRO PP150 was used in assembling shear wall. The Simpson screw system can avoid over-drilling by setting the drive depth. Before drilling, the driver was tested to set the driving depth. Typical results are shown in Figure 11. Details of the employed

fasteners follow:

(a)Stud to track:

No.10×¾ in. Flat head Quick Drive FPHSD34S1016.

(b)Back to back stud:

No.10×1in.X1S1016 Quick Drive 5/16 Hex Drive Drill point, 16TPI Blue-bright Zinc.

(c) OSB to stud /track:

No.8×1 15/16 in. Quick Drive PPSD1151S0818

(d) Gypsum board to stud:

No.6×1 5/8 in. Quick Drive DWFSD158PS

(e)Clip to stud and cold rolled channel to clip

No.8×1in.Phil Flat Tek

(f) Hold-down to stud:

No.14×1in. HWT Self-Drilling

(g) Shear Anchor bolts

5/8-in. diameter ASTM A325 anchor bolts with standard cut washers and nuts. Four bolts were used for each 4ft.×9ft. shear wall assembly. Six bolts for each 8ft×9ft shear walls.

Figure 11 Appropriate fastening in OSB and gypsum board

End Gap:

The gap between chord studs and track were measured prior to the test at the locations designated in Figure 12 and the amounts provided in Table 3.

Figure 12 Location of measured gaps

Table 3 Measured gaps between chord stud and track

Test label	Gap1(in.)	Gap2(in.)	Gap3(in.)	Gap4(in.)
1c	0.08	0.117	0.041	0.059
2	0.03	0.072	0.026	0.153
3	0.097	0.16	0.063	1.054
4	0.065	0.145	0.027	0.078
5	0.137	0.177	0.031	0.093
6	0.133	0.079	0.101	0.072
7	0.037	0.132	0.063	0.087
8	0.047	0.049	0.033	0.101
9	0.039	0.061	0.038	0.077
10	0.052	0.047	0.072	0.086
11c	0.116	0.1	0.102	0.084
12	0.065	0.128	0.143	0.091
13	0.034	0.075	0.083	0.071
14	0.083	0.145	0.078	0.065
15	0.025	0.137	0.148	0.12

Note: test 16 reused stud to track frame of test 12.

2.4 Material Properties

Coupon tests of the stud and track material were conducted on an INSTRON®4482 universal testing machine according to the ASTM A370 (2006) "Standard Test Methods and Definitions for Mechanical Testing of Steel Products." Three coupon specimens were tested for each member, and the average results are summarized in Table 4. The coating on the steel was removed by hydrochloric acid prior to the coupon tests. An INSTRON®2630-106extensometer was employed to measure the tensile strain. The tests were conducted in displacement control at a constant rate of 0.05 in./min.

Table 4 Coupon test summary

Components	**Uncoated thickness (in.)**	**Yield stress F_y (ksi)**	**Tensile strength F_u (ksi)**	**F_u/F_y**	**Elongation for 2 in. gage length(%)**
54mil-50ksi stud	0.0566	56.1	78.8	1.40	14.9%
54mil-50ksi track	0.0583	64.3	72.4	1.13	16.5%
54mil-50ksi stud*	0.0570	54.5	74.2	1.36	27.6%
33mil-33ksi stud	0.0365	51.5	59.9	1.16	18.0%
54mil-33ksi stud	0.0564	55.3	79.4	1.43	19.1%
97mil-50ksi ledger	0.1014	45.4	61.5	1.35	30.5%

Note: 54mil-50ksi stud* is the second set of purchased studs which were used in all the 8ft x 9ft shear walls as a field stud.

3 Test Results

Individual test information and tests results, including hysteretic performance, are supplied for each conducted test in Appendix B. A summary of the primary results are provided in Table 5.

Table 5 Summary of the result

Test	**Peak Load**		**Lateral Deflection at Peak**		**Avg. Load[1]**	**Avg. Disp[2]**	**Failure Mode[3]**
quantity	*P+*	*P-*	*Δ+*	*Δ-*	P_{ave}	Δ_{ave}	
unit	plf	plf	in.	in.	plf	in.	-
1c	1225	-	2.96	-	1225	2.96	PT
2	1160	1044	2.92	2.71	1102	2.82	PT
3	1265	958	2.87	2.44	1111	2.67	PT
4	1046	963	2.88	1.93	1004	2.40	PT
5	1023	950	2.83	1.96	987	2.39	PT
6	1232	830	2.78	1.69	1031	2.24	PT
7*	876	918	2.55	1.91	897	2.23	PT
8*	1036	929	3.66	3.00	982	3.33	PT
9	921	890	4.20	2.92	906	3.56	PT
10	951	950	2.91	2.98	950	2.95	PT
11c	1089	-	2.42	-	1089	2.42	PT+B
12	1256	1055	2.27	1.66	1156	1.96	PT+B
13	1327	1138	2.20	1.62	1232	1.91	PT+B
14	1056	990	2.22	1.66	1023	1.94	PT+B
15	883	839	1.62	1.67	861	1.64	PT
16	259	202	1.22	1.73	231	1.47	PT

[1]Average of P+ and P-, [2]Average of Δ+ and Δ-, [3]PT = fastener pull-through and B = fastener bearing
*Additional filed stud 1'over from side

Specimens typically failed at perimeter and corner sheathing-to-stud fastener locations. The final column of Table 5 summarizes the basic (most common) failure mode as either a pull-through (PT) or bearing (B) failure. Screw shear (designated as cut off in the test summary data sheets) was observed in isolated cases. The complete suite of observed failure modes are shown in Figure 13. The recorded failure modes, for every failed fastener, are provided in Appendix A.

(a) pull-through (PT)

(b) wood bearing failure (WB)

(c) tear out of sheathing (TO)

(d) cut off head (screw shear)

(e) enlarged hole

(f) partiall pull through (PPT)

Figure 13 Observed fastener-sheathing modes of failure, pull-through (a,f), bearing (b,c,e) screw shear (d)

Tested capacities are sensitive to the practical details studied: peak strength varies by 30% across the tested details. If one rejects the use of lower thickness field studs and does not account for gypsum board then the spread reduces to 22% across specimens, with the ledger track (beneficial) and vertical seams (detrimental) providing the most important source for the remaining spread. With the exception of the lower thickness field stud case, tested capacities exceed or are within expected scatter (5%) of the AISI-S213-07 specified shear strength.

Initial post-processing of the test results, establishing the backbone curve and the Equivalent Energy Elastic Perfectly Plastic (EEEP) properties was completed soon after the testing and is provided in Appendix C. Full hysteretic characterization, which includes pinching, provides a more useful characterization than EEEP. Subsequent work beyond the scope of this test report will provide the complete hysteretic characterization.

4 Conclusions

A series of cyclic (CUREE protocol) tests were conducted on cold-formed steel shear walls with the specific objective of understanding the influence of details that are employed in practical construction that deviate from conventionally tested walls. The baseline wall consisted of back-to-back 54 mil cold-formed steel chord studs with 7/16 in. OSB sheathing and fasteners spaced 6 in. on center. Practical details examined included studies of the influence of: ledger (rim track), interior gypsum board, horizontal and vertical panel seams within the wall, and the use of lower thickness and grade studs in the field of the wall. Tested capacities are sensitive to practical details: peak strength varies by 30% across the tested details. If one rejects the use of lower thickness field studs and does not account for gypsum board then the spread reduces to 22%, with the ledger track (beneficial) and vertical seams (detrimental) providing the most important source for the remaining spread. Tested capacities exceed or are within expected scatter (5%) of the AISI-S213-07 specified shear strength.

As of this writing the following supplementary papers related to this work expand upon the test results provided here:

Liu, P., Peterman, K.D., Yu, C., Schafer, B.W. (2012). "Cold-formed steel shear walls in ledger-framed buildings" Proceedings of the Annual Stability Conference, Structural Stability Research Council, Grapevine, Texas, April 18-21, 2012.

Liu, P., Peterman, K.D., Yu, C., Schafer, B.W. (2012). "Characterization of cold-formed steel shear wall behavior under cyclic loading for the CFS-NEES building" Proceedings of the International Specialty Conference on Cold-Formed Steel Structures, Center for Cold-Formed Steel Structures, St, Louis, Missouri, October 24-25, 2012. (Accepted)

Complementary work related to the CFS-NEES project, under which this work was conducted is available at: www.ce.jhu.edu/cfsnees.

5 References

AISI-S200-07 (2007). North American Standard for Cold-Formed Steel Framing – General Provisions. American Iron and Steel Institute, Washington, D.C., AISI-S200-07.

AISI-S213-07 (2007). North American Standard for Cold-Formed Steel Framing – Lateral Provisions. American Iron and Steel Institute, Washington, D.C., AISI-S213-07

ASTM E2126 (2011). "Standard Test Methods for Cyclic (Reversed) Load Test for Shear Resistance of Vertical Elements of the Lateral Force Resisting Systems for Buildings," ASTM International, West Conshohocken, PA, 2006, DOI: 10.1520/E2126-11, www.astm.org.

ASTM E564 (2006). "Standard Practice for Static Load Test for Shear Resistance of Framed Walls for Buildings," ASTM International, West Conshohocken, PA, 2006, DOI: 10.1520/E0564-06, www.astm.org.

6 Acknowledgement

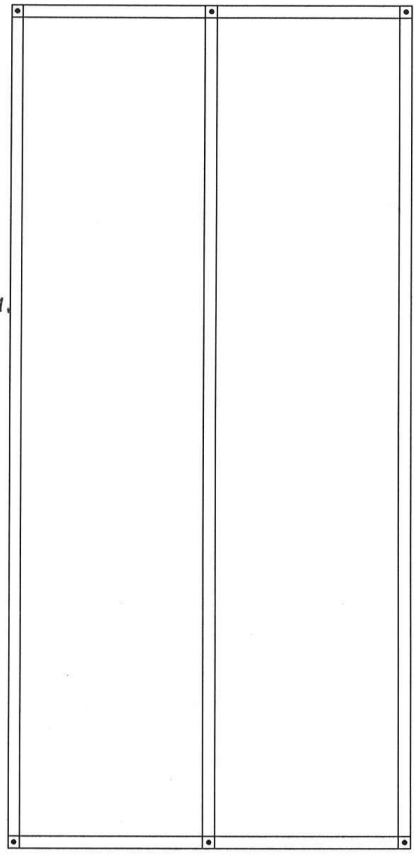
The donation of materials by ClarkDietrich™ Building Systems and Simpson Strong-Tie Company, Inc. are acknowledged. The shear wall test program was conducted at the University of North Texas. A special thanks to Roger Rovira, Marcus Sanchez, Noritsugu Yanagi for the help during the shear wall assembling and testing. This report was prepared as part of the U.S. National Science Foundation sponsored CFS-NEES project: NSF-CMMI-1041578: NEESR-CR: Enabling Performance-Based Seismic Design of Multi-Story Cold-Formed Steel Structures. The project also received supplementary support and funding from the American Iron and Steel Institute. Project updates are available at www.ce.jhu.edu/cfsnees. Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the National Science Foundation, nor the American Iron and Steel Institute.

Appendix A Data Sheets

Johns Hopkins University

Test name: 1a-4'x9'-54mil
Date tested: OCT. 27. 2011
Wall size: 4'x9'
With ledger: ☐ Yes ☒ No
Test mode: ☒ Stiffness

Apply load^{+} 100lbs
load^{-} -100lbs
Manually
Stiffness : 51.15 lbs/in.



Johns Hopkins University

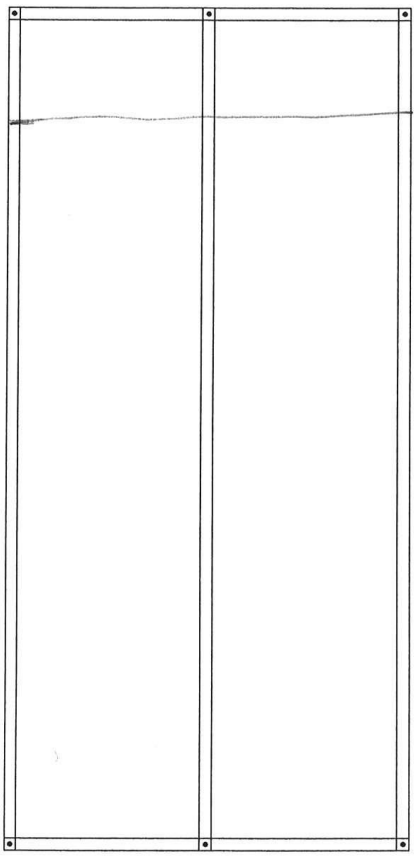
Test name: Lb-4'x9'-Ledger-Stiff
Date tested: OCT. 28. 2011
Wall size: 4'x9'
With ledger: ☒ Yes ☐ No
Test mode: ☒ Stiffness

Apply load + 20 lbs

Ap load - -20 lbs

Manually

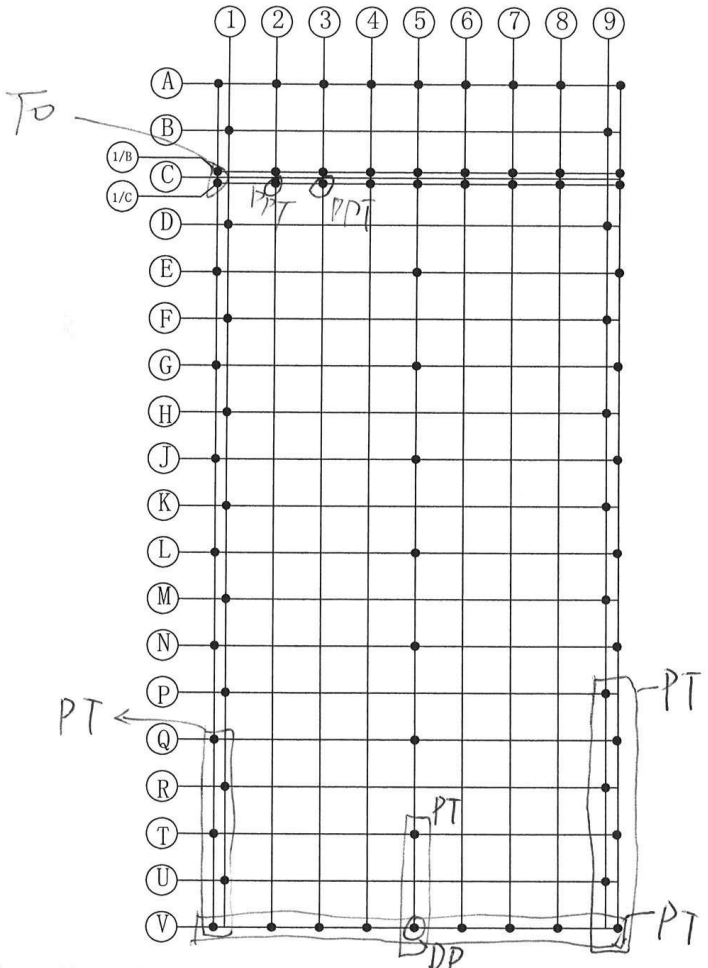
Stiffness: 105.8 lbs/in



Johns Hopkins University

1-4'x9'-ledger-OSB-54mil-8'upseam

Test name: 1C
Date tested: Nov. 2, 2011
Wall size: 4'x9'
With ledger: ☒ Yes ☐ No
Test mode: ☐ Cyclic ☒ Monotonic

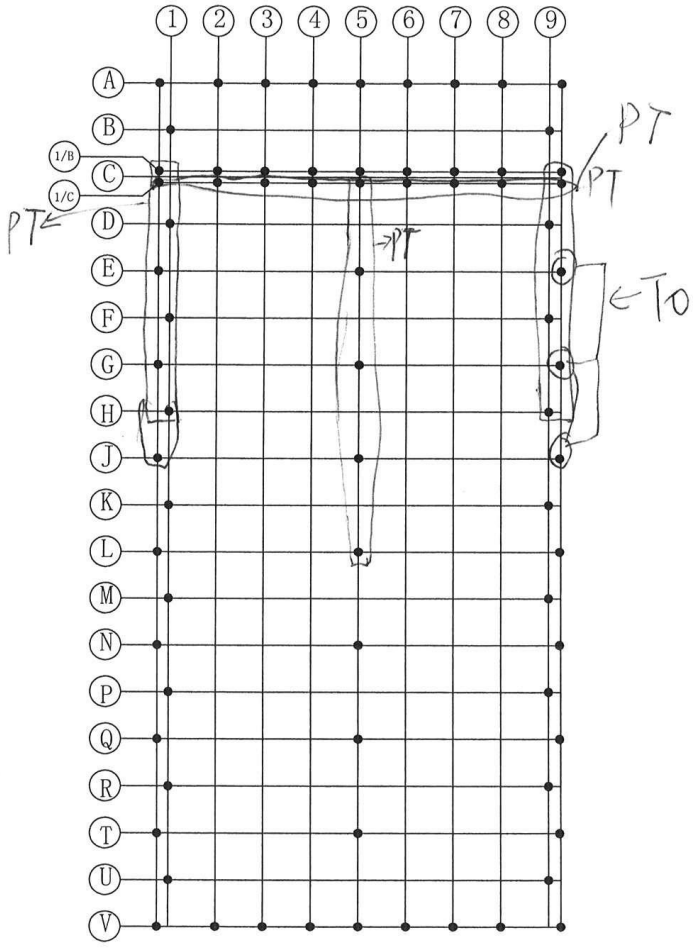


Failure mode: Pullout,withdrawal(PO);Fatigue Fracture Failure(FF);Pull through sheathing(PT); Damage prior to testing(DP);Partial Pull through(PPT);Tearout of sheathing(TO); Wood Bearing Failure(WB);No Damage(ND)

Johns Hopkins University

Test name: 2
Date tested: Nov. 2, 2011
Wall size: 4'x9'
With ledger: ☒Yes ☐No
Test mode: ☒Cyclic ☐Monotonic

2 - 4'x9'-Ledger-OSB-54mil-8"up seam

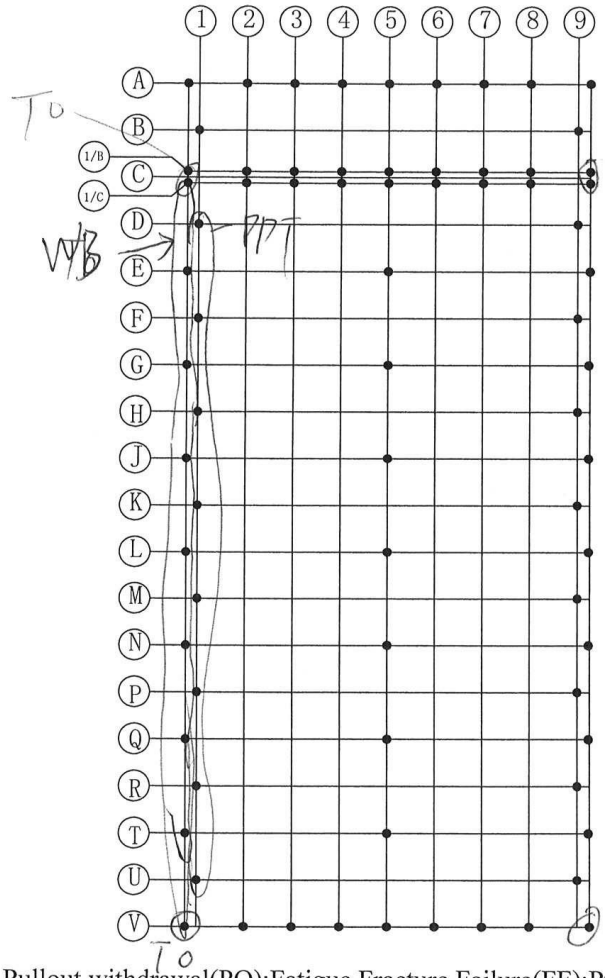


Failure mode: Pullout,withdrawal(PO);Fatigue Fracture Failure(FF);Pull through sheathing(PT); Damage prior to testing(DP);Partial Pull through(PPT);Tearout of sheathing(TO); Wood Bearing Failure(WB);No Damage(ND)

Johns Hopkins University

Test name: 3
Date tested: Nov. 3, 2011
Wall size: 4'x9'
With ledger: ☒ Yes ☐ No
Test mode: ☒ Cyclic ☐ Monotonic

3-4'x9'-ledger-OSB-GYP-54mil-Zip seam



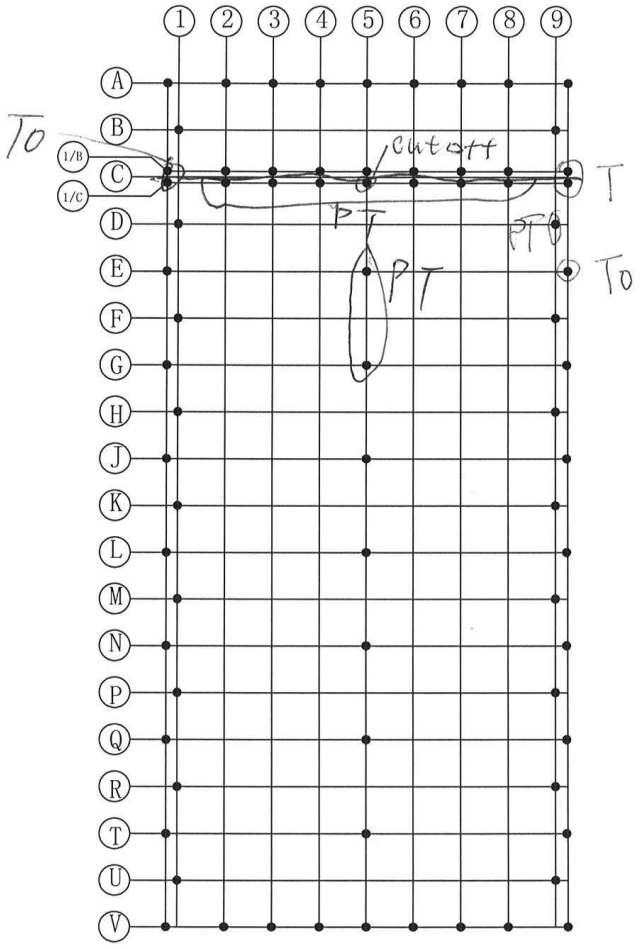
NO Fasteners fail on the ~~1st~~ Field Stud

Failure mode: Pullout,withdrawal(PO);Fatigue Fracture Failure(FF);Pull through sheathing(PT); Damage prior to testing(DP);Partial Pull through(PPT);Tearout of sheathing(TO); Wood Bearing Failure(WB);No Damage(ND)

Johns Hopkins University

4-4'x9'-OSB-54mil-8'np seam

Test name: 4
Date tested: Nov. 7, 2011
Wall size: 4'x9'
With ledger: ☐ Yes ☒ No
Test mode: ☒ Cyclic ☐ Monotonic

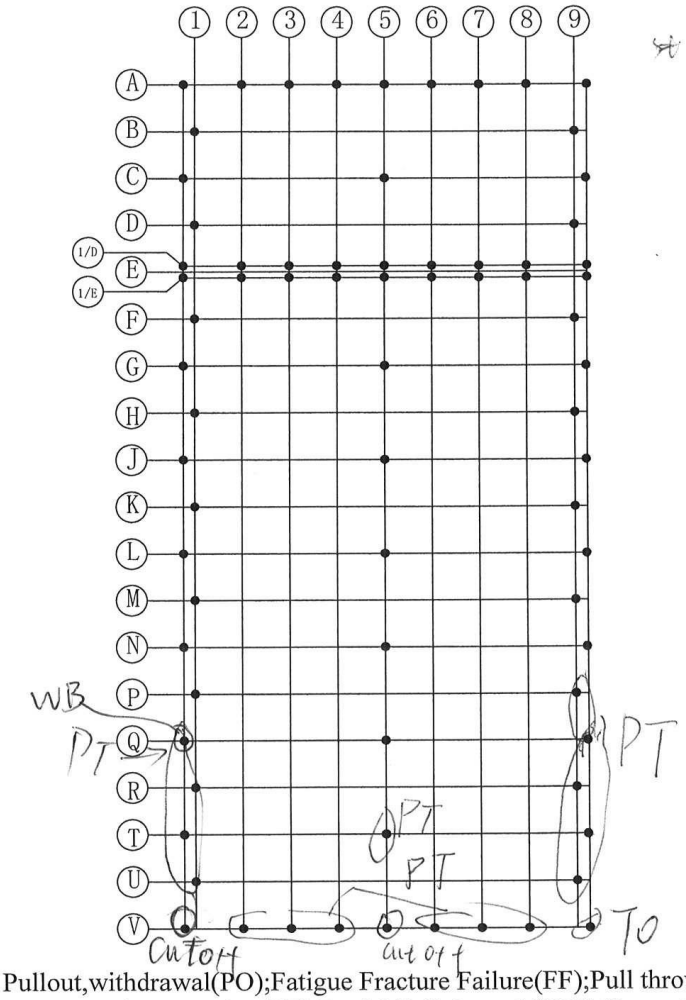


Failure mode: Pullout,withdrawal(PO);Fatigue Fracture Failure(FF);Pull through sheathing(PT);
Damage prior to testing(DP);Partial Pull through(PPT);Tearout of sheathing(TO);
Wood Bearing Failure(WB);No Damage(ND)

Johns Hopkins University

Test name: 5
Date tested: Nov. 10, 2011
Wall size: 4'x9'
With ledger: ☒ Yes ☐ No
Test mode: ☒ Cyclic ☐ Monotonic

5 - 4'x9' - Ledger - OSB - 54mil - 7"ups



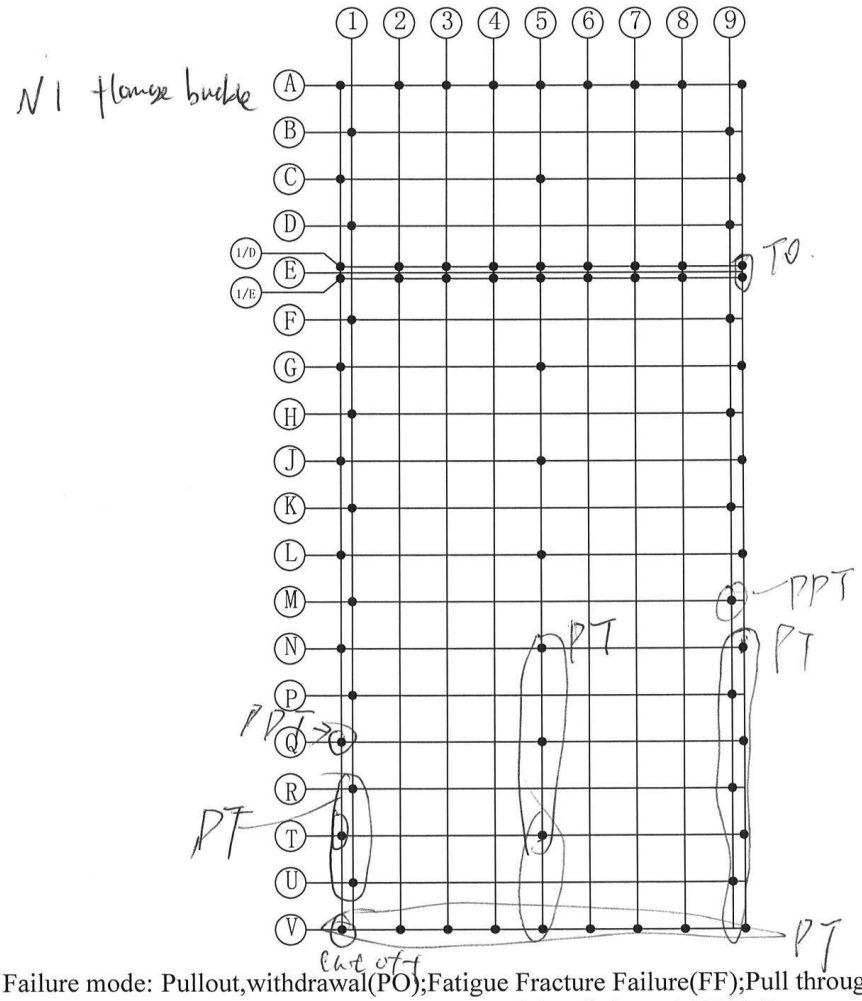
* seam is good

Failure mode: Pullout,withdrawal(PO);Fatigue Fracture Failure(FF);Pull through sheathing(PT); Damage prior to testing(DP);Partial Pull through(PPT);Tearout of sheathing(TO); Wood Bearing Failure(WB);No Damage(ND)

Johns Hopkins University

6-4'x9'-OSB-54mil-7'up seam.

Test name: 6
Date tested: Nov. 10, 2011
Wall size: 4'x9'
With ledger: ☐ Yes ☒ No
Test mode: ☒ Cyclic ☐ Monotonic

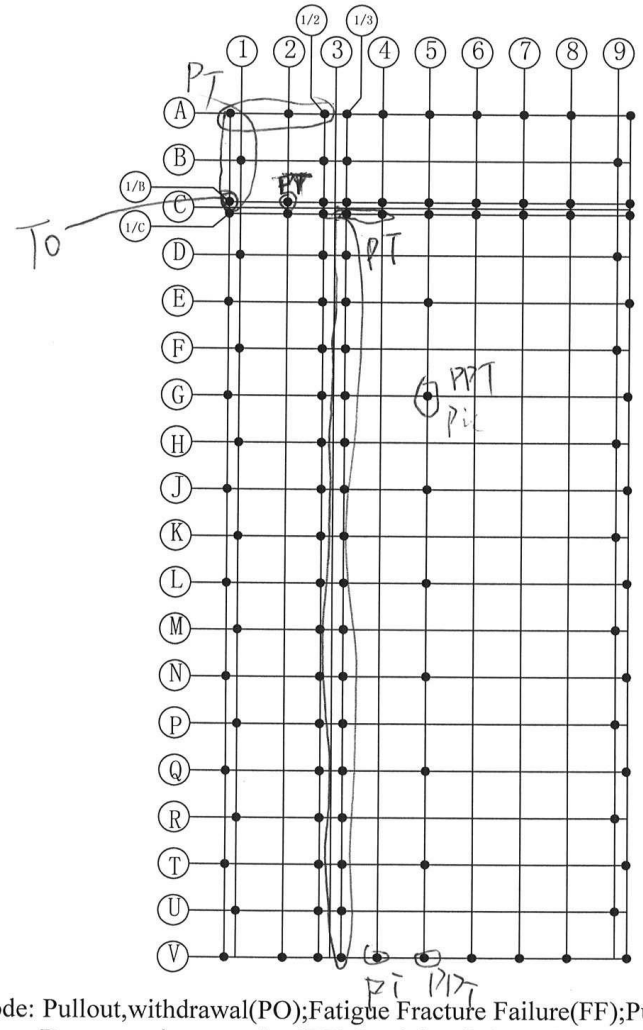


Failure mode: Pullout,withdrawal(PO);Fatigue Fracture Failure(FF);Pull through sheathing(PT); Damage prior to testing(DP);Partial Pull through(PPT);Tearout of sheathing(TO); Wood Bearing Failure(WB);No Damage(ND)

Johns Hopkins University

Test name: 7
Date tested: Nov. 17, 2011
Wall size: 4'x9'
With ledger: ☐ Yes ☒ No
Test mode: ☒ Cyclic ☐ Monotonic

7-4'x9'-OSB-5-4mil-1'over-8'up Sec

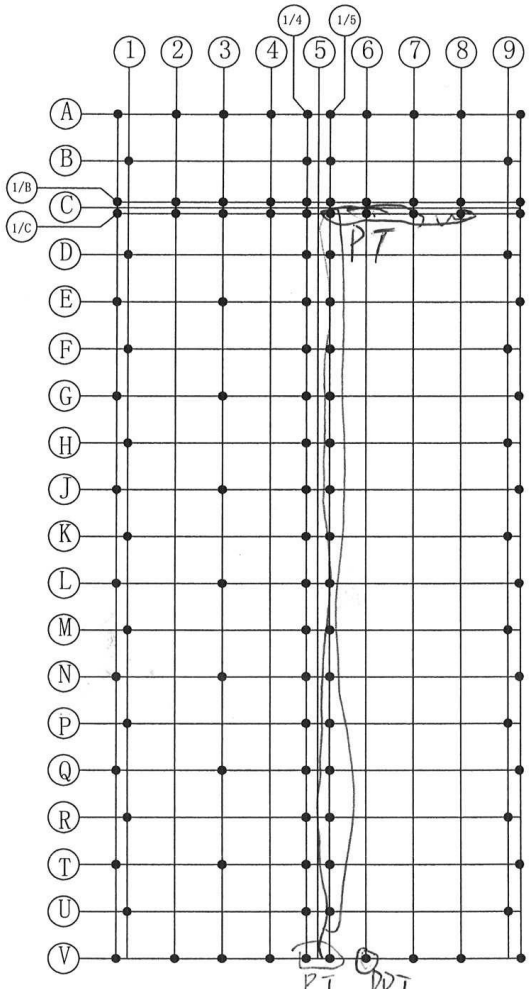


Failure mode: Pullout,withdrawal(PO);Fatigue Fracture Failure(FF);Pull through sheathing(PT); Damage prior to testing(DP);Partial Pull through(PPT);Tearout of sheathing(TO); Wood Bearing Failure(WB);No Damage(ND)

Johns Hopkins University

Test name: 8
Date tested: Nov. 18, 2011
Wall size: 4'x9'
With ledger: ☐ Yes ☒ No
Test mode: ☒ Cyclic ☐ Monotonic

8 - 4x9 - OSB - 54mil - 2' over - 8' up seam



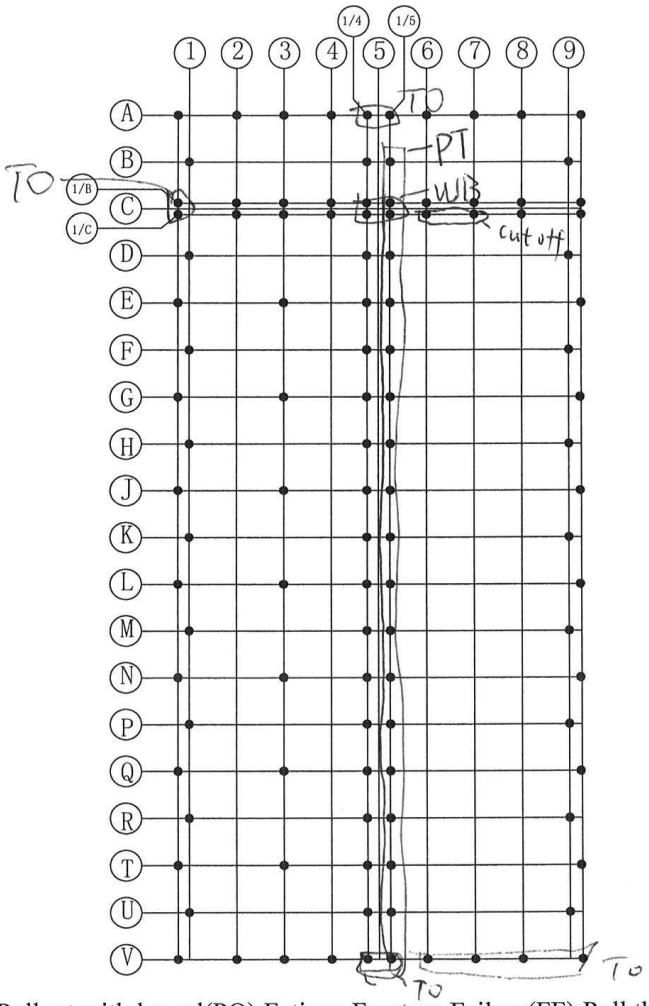
Observe

Failure mode: Pullout,withdrawal(PO);Fatigue Fracture Failure(FF);Pull through sheathing(PT); Damage prior to testing(DP);Partial Pull through(PPT);Tearout of sheathing(TO); Wood Bearing Failure(WB);No Damage(ND)

Johns Hopkins University

Test name: 9
Date tested: Nov. 18, 2011
Wall size: 4'x9'
With ledger: ☐ Yes ☒ No
Test mode: ☒ Cyclic ☐ Monotonic

9_4X9_OSB-54mil-2'over-8'upseam

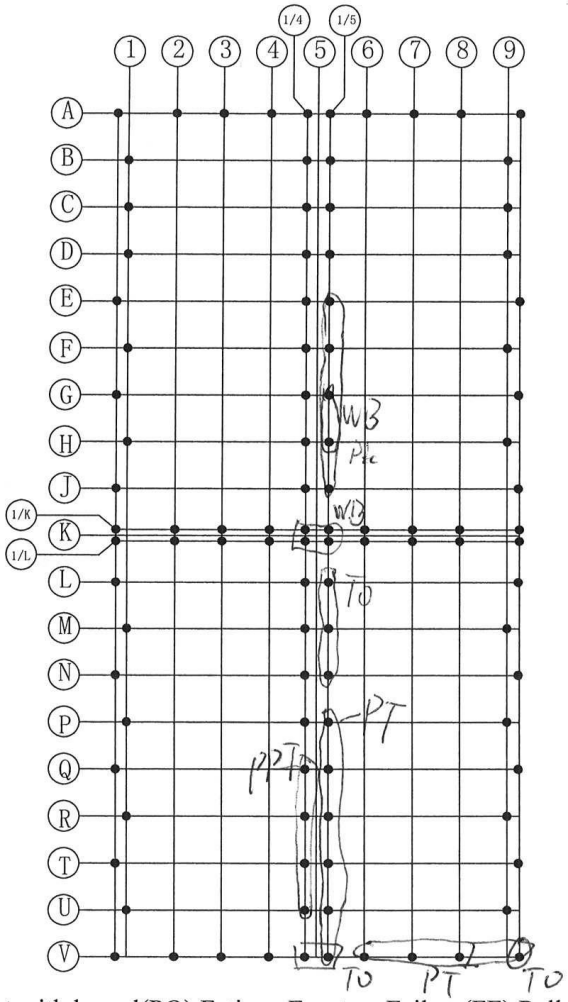


Failure mode: Pullout,withdrawal(PO);Fatigue Fracture Failure(FF);Pull through sheathing(PT); Damage prior to testing(DP);Partial Pull through(PPT);Tearout of sheathing(TO); Wood Bearing Failure(WB);No Damage(ND)

Johns Hopkins University

10_4'x9'-0513-54mil-4.5'over-4.5'upSpan

Test name: 10
Date tested: Nov. 18, 2011
Wall size: 4'x9'
With ledger: ☐ Yes ☒ No
Test mode: ☒ Cyclic ☐ Monotonic



Failure mode: Pullout,withdrawal(PO);Fatigue Fracture Failure(FF);Pull through sheathing(PT); Damage prior to testing(DP);Partial Pull through(PPT);Tearout of sheathing(TO); Wood Bearing Failure(WB);No Damage(ND)

Johns Hopkins University

Test name: 11a-8'x9'-5psi
Date tested: Oct. 28. 2011
Wall size: 8'x9'
With ledger: ☐ Yes ☒ No
Test mode: ☒ Stiffness

Johns Hopkins University

Test name: 11a - 8'x9' - Ledger - Static
Date tested: Nov. 28, 2011
Wall size: 8'x9'
With ledger: ☒ Yes ☐ No
Test mode: ☒ Stiffness

Apply load + 150 lbs

Load - 150 lbs

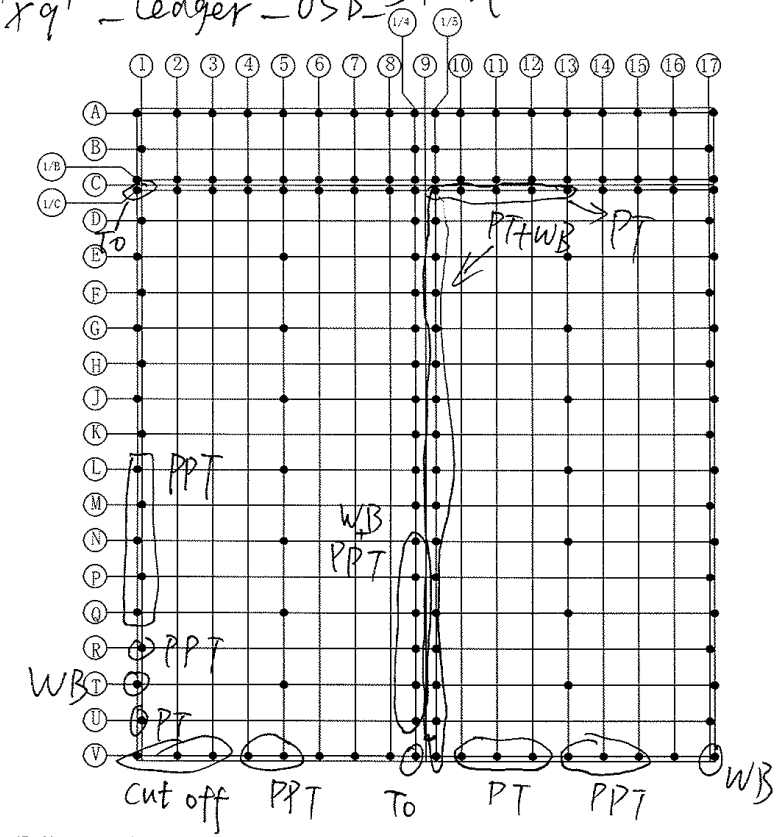
Stiffness:

166.6 lbs/in

Johns Hopkins University

11C – 8'x9' _ ledger _ OSB _ 54m/M

Test name: 11C
Date tested: 12/2/2011
Wall size: 8' X 9'
With ledger: ☒ Yes ☐ No
Test mode: ☐ Cyclic ☒ Monotonic

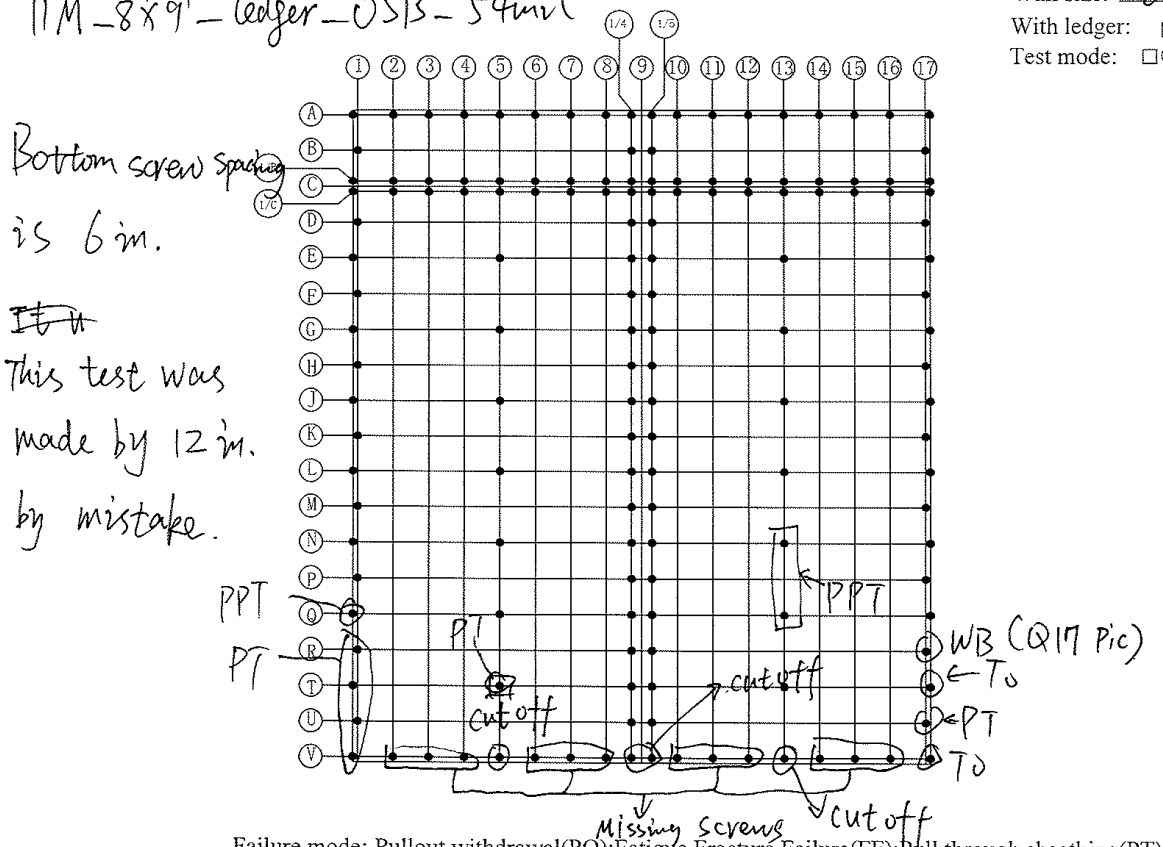


Failure mode: Pullout,withdrawal(PO);Fatigue Fracture Failure(FF);Pull through sheathing(PT);
Damage prior to testing(DP);Partial Pull through(PPT);Tearout of sheathing(TO);
Wood Bearing Failure(WB);No Damage(ND)

Johns Hopkins University

Test name: 11M
Date tested: 11/30/2011
Wall size: 8'X9'
With ledger: ☒Yes ☐No
Test mode: ☐Cyclic ☒Monotonic

11M_8'x9'_ledger_OSB_54mil

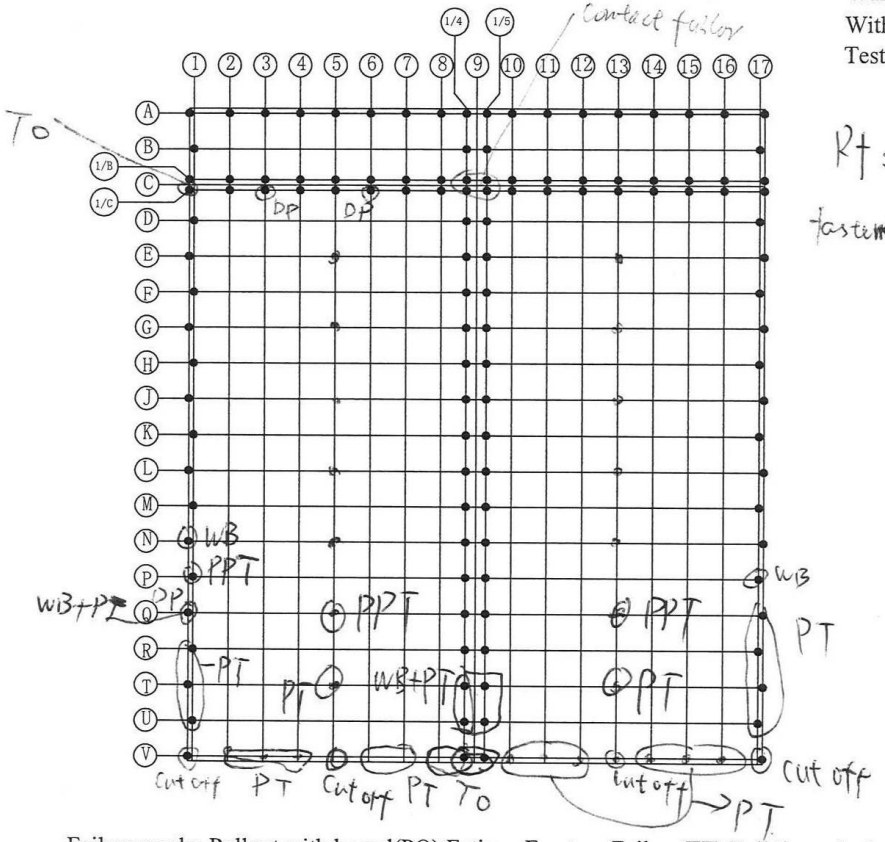


Failure mode: Pullout,withdrawal(PO);Fatigue Fracture Failure(FF);Pull through sheathing(PT);
Damage prior to testing(DP);Partial Pull through(PPT);Tearout of sheathing(TO);
Wood Bearing Failure(WB);No Damage(ND)

Johns Hopkins University

Test name: 12
Date tested: 12/6/2011
Wall size: 8' x 9
With ledger: ☒ Yes ☐ No
Test mode: ☒ Cyclic ☐ Monotonic

43 cycles
Rt: 2.92 x 0.6 in.
fasteners at strap is good

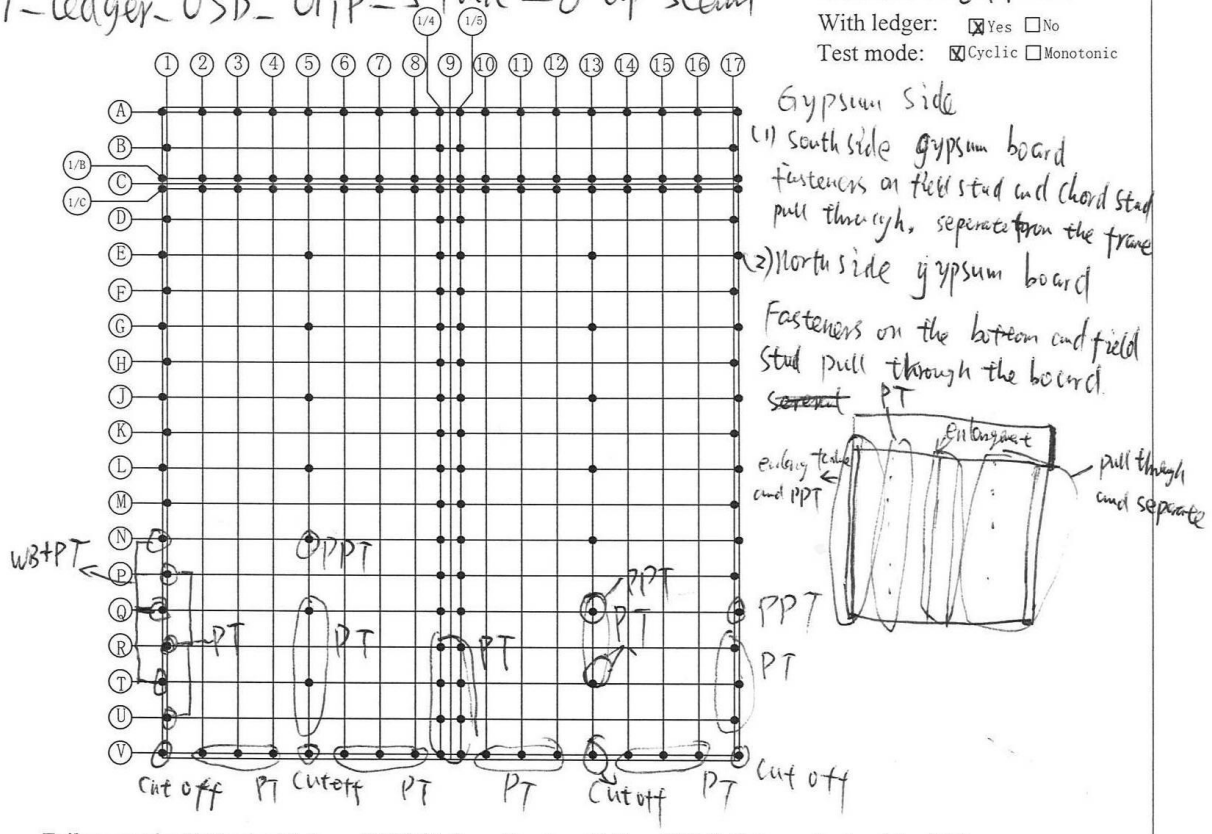


Failure mode: Pullout,withdrawal(PO);Fatigue Fracture Failure(FF);Pull through sheathing(PT);
Damage prior to testing(DP);Partial Pull through(PPT);Tearout of sheathing(TO);
Wood Bearing Failure(WB);No Damage(ND)

Johns Hopkins University

13_8x9_ledger_OSB_GYP_54mil_8'up seam

Test name: 13
Date tested: 12/7/2011
Wall size: 8X9
With ledger: ☒ Yes ☐ No
Test mode: ☒ Cyclic ☐ Monotonic



Gypsum side

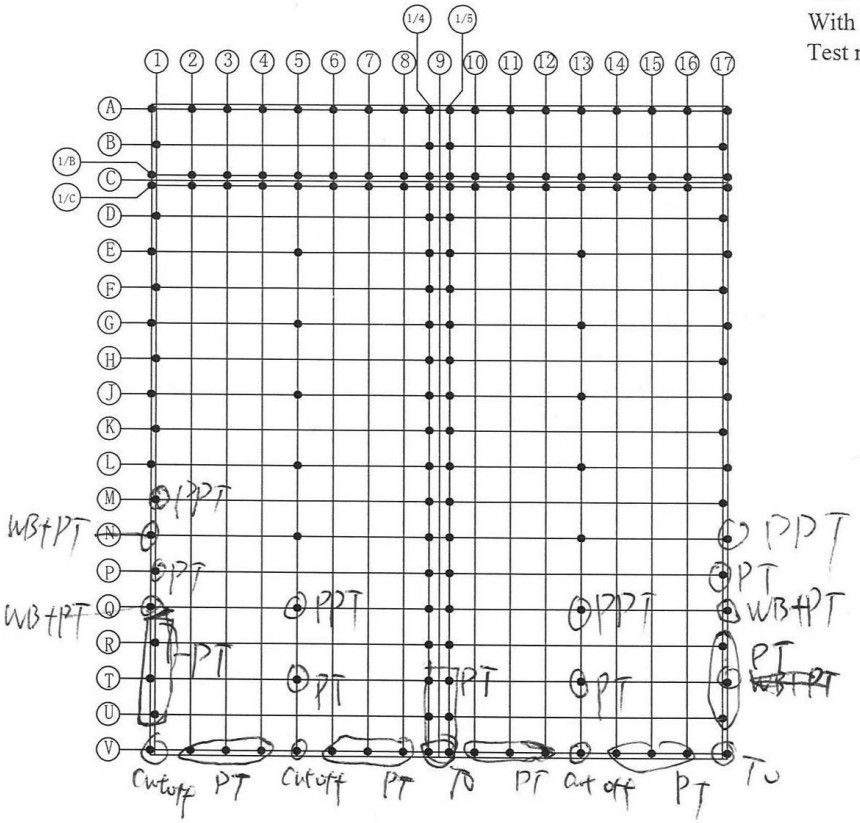
(1) South side gypsum board fasteners on field stud and chord stud pull through, seperate from the frame

(2) North side gypsum board Fasteners on the bottom and field stud pull through the board

Failure mode: Pullout,withdrawal(PO);Fatigue Fracture Failure(FF);Pull through sheathing(PT);
Damage prior to testing(DP);Partial Pull through(PPT);Tearout of sheathing(TO);
Wood Bearing Failure(WB);No Damage(ND)

Johns Hopkins University

Test name: 14
Date tested: 12/8/2011
Wall size: 8'x9'
With ledger: ☐ Yes ☒ No
Test mode: ☒ Cyclic ☐ Monotonic

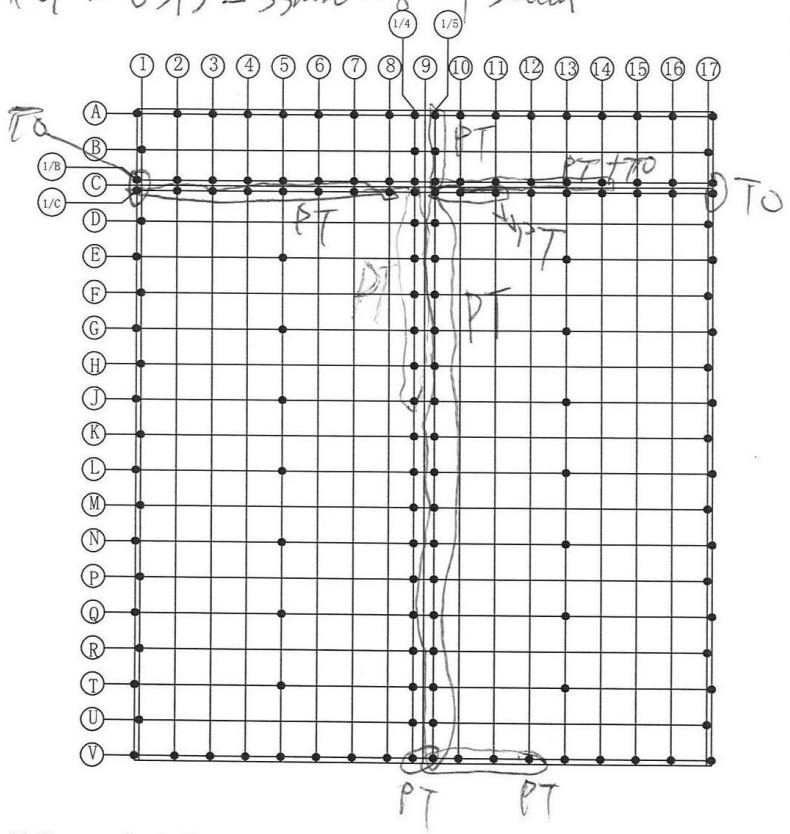


Failure mode: Pullout,withdrawal(PO);Fatigue Fracture Failure(FF);Pull through sheathing(PT);
Damage prior to testing(DP);Partial Pull through(PPT);Tearout of sheathing(TO);
Wood Bearing Failure(WB);No Damage(ND)

Johns Hopkins University

15_8'x9'-0513-33mil-8'up seam

Test name: 15
Date tested: 12/9/2011
Wall size: 8'x9'
With ledger: ☐ Yes ☒ No
Test mode: ☒ Cyclic ☐ Monotonic

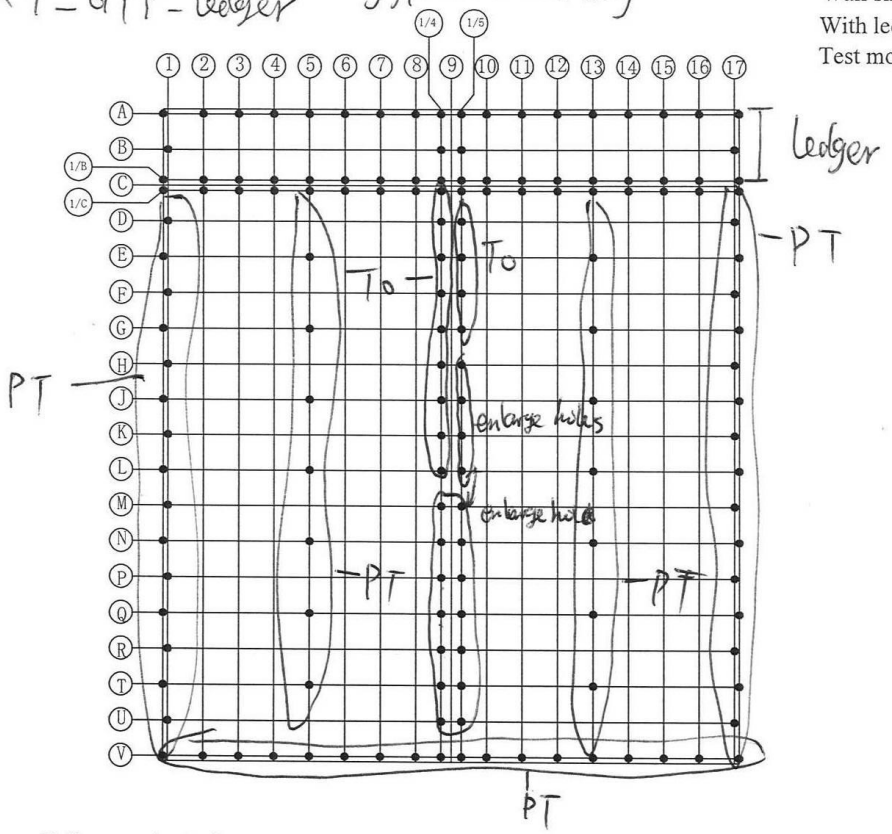


Failure mode: Pullout,withdrawal(PO);Fatigue Fracture Failure(FF);Pull through sheathing(PT);
Damage prior to testing(DP);Partial Pull through(PPT);Tearout of sheathing(TO);
Wood Bearing Failure(WB);No Damage(ND)

Johns Hopkins University

8×9_GYP_ledger gypsum board only

Test name: 16
Date tested: 12/13/2011
Wall size: 8×9
With ledger: ☒ Yes ☐ No
Test mode: ☒ Cyclic ☐ Monotonic



Failure mode: Pullout,withdrawal(PO);Fatigue Fracture Failure(FF);Pull through sheathing(PT);
Damage prior to testing(DP);Partial Pull through(PPT);Tearout of sheathing(TO);
Wood Bearing Failure(WB);No Damage(ND)

Appendix B Test summaries

Test Label 1a-4x9-54mil

Test Date: OCT. 27, 2011

Specimen Configuration

Shear walls, back to back studs 600S162-54mil(50ksi), Track: 600T150-54mil(50ksi), Simpson S/HDU6 hold downs, ledger: 1200T200-97mil(50ksi)

Wall dimensions: 4 ft. ×9ft. Loading type: K Ledger: No

Front sheathing: Bare Rated sheathing: N/A Back sheathing: Bare.

Fastener: Back to back studs: #10x1" Hex washer head Fastener spacing: 12in.

Track to stud: #10x3/4" flat head .

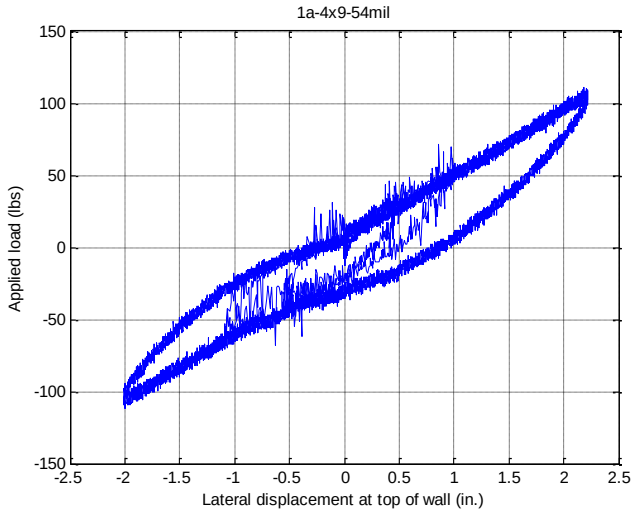
Hold downs: #14x1"Hex washer head Quantity: 12

Field studs: 600S162-54mil (50ksi) Wall bracing: Clip: 1-1/2"x1-1/2"x54-mil Cold rolled channel: 1-1/2"x54-mil

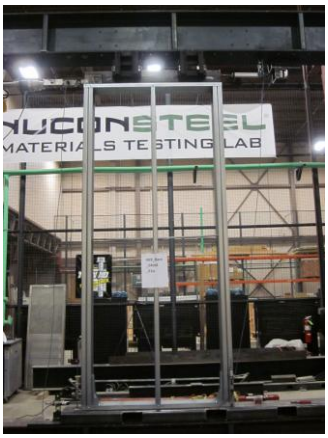
Test results

load: 111.4lbs

Net lateral displacement at top of frame: 2.182in.



Stiffness of the frame: 51.15lbs/in.



Test Label 1b-4x9-Ledger-54mil

Test Date: OCT. 28, 2011

Specimen Configuration

Shear walls, back to back studs 600S162-54mil(50ksi), Track: 600T150-54mil(50ksi), Simpson S/HDU6 hold downs, ledger: 1200T200-97mil(50ksi)

Wall dimensions: 4 ft. ×9ft. Loading type K. Ledger: Yes

Front sheathing: Bare Rated sheathing: N/A Back sheathing: Bare.

Fastener: Back to back studs: #10x1'' Hex washer head Fastener spacing: 12in.

Track to stud: #10x3/4'' flat head .

Hold downs: #14x1''Hex washer head Quantity: 12.

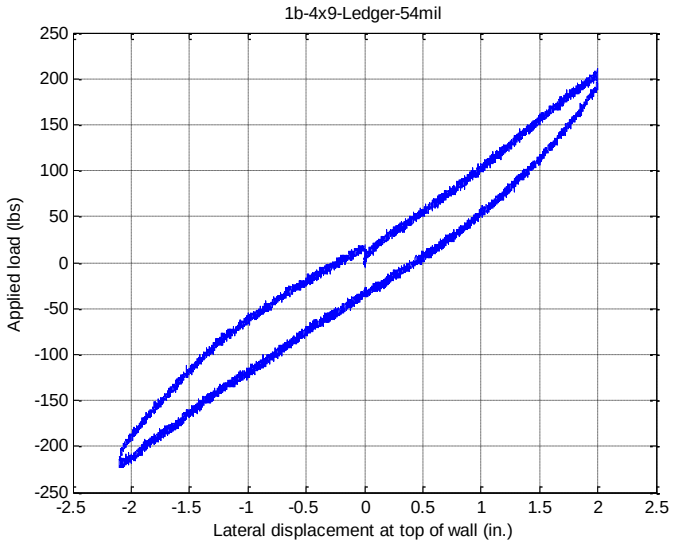
Field studs: 600S162-54mil (50ksi)

Wall bracing: Clip: 1-1/2"x1-1/2"x54mil Cold rolled channel: 1-1/2"x54mil

Test results

load: 211.0lbs

Net lateral displacement at top of frame: 1.991in.



Stiffness of the frame: 105.8lbs/in.

Test Label 1c-4x9-Ledger–OSB-54mil-8'up seam Test Date: Nov.11, 2011

Specimen Configuration

Shear walls, back to back studs 600S162-54mil (50ksi), Track: 600T150-54mil(50ksi), Simpson S/HDU6 hold downs, ledger: 1200T200-97mil(50ksi)

Wall dimensions: 4 ft. ×9ft. Loading type: Monotonic Ledger: No

Front sheathing: OSB Rated sheathing: APA 24/16 exposure 1 OSB Thickness: 7/16''

Back sheathing: Bare.

Fastener: Back to back studs: #10×1'' Hex washer head Fastener spacing:12in.

Track to stud: #10×3/4'' flat head .

Hold downs: #14×1''Hex washer head Quantity: 12

OSB to stud: #8x1-15/16'' flat head Fastener spacing: 6 in.

Clip to cold rolled channel: #8-3/4'' flat head

Gypsum to stud: N/A

Field studs: 600S162-54mil (50ksi) Horizontal seam location: 8'up Vertical seam location: No

Strap: 1-1/2''-54mil

Wall bracing: Clip:1-1/2"×1-1/2"×54mil Cold rolled channel:1-1/2"×54mil

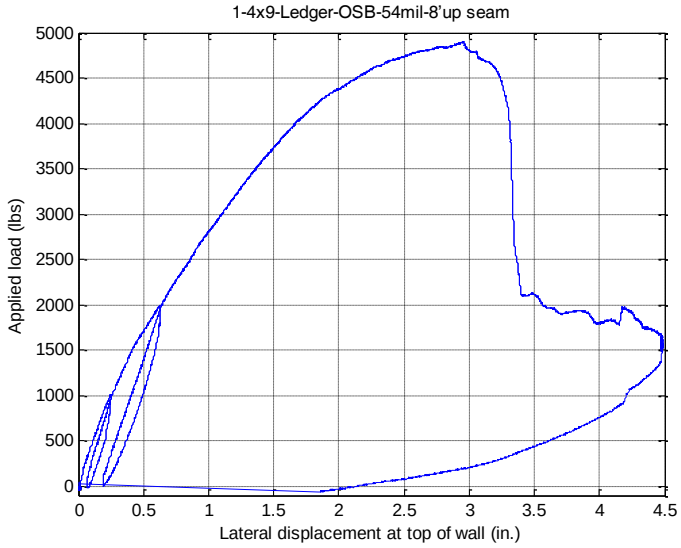
Environmental info (that day average): Temperature: 77F, Humidity:43%

Test results

Maximum +load:1225plf

Maximum +load: 4902lbf

Net lateral displacement at top of wall at Maximum +load: 2.963in.



Observed Failure Mode: Failure occurred at bottom with fasteners tilted and pulled through the OSB.

Front side

Back side

Bottom (North)

Bottom (South)

Bottom fasteners (North)

Bottom fasteners (South)

Strap

Hold down (South)

Hold down (North)

Test Label 2-4x9-Ledger-OSB-54mil-8'up seam Test Date:Nov.2, 2011

Specimen Configuration

Shear walls, back to back studs 600S162-54mil(50ksi), Track: 600T150-54mil(50ksi), Simpson S/HDU6 hold downs, ledger: 1200T200-97mil(50ksi)

Wall dimensions: 4 ft. ×9ft. Loading type: Cyclic Ledger: Yes

Front sheathing: OSB Rated sheathing: APA 24/16 exposure 1 OSB Thickness: 7/16"

Back sheathing: Bare.

Fastener: Back to back studs: #10×1" Hex washer head Fastener spacing:12in.

Track to stud: #10×3/4" flat head .

Hold downs: #14×1"Hex washer head Quantity: 12

OSB to stud: #8x1-15/16" flat head Fastener spacing: 6 in.

Clip to cold rolled channel: #8-3/4" flat head

Gypsum to stud: N/A

Field studs: 600S162-54mil (50ksi) Horizontal seam location: 8'up Vertical seam location: No

Strap: 1-1/2"-54mil

Wall bracing: Clip: 1-1/2"×1-1/2"×54mil Cold rolled channel: 1-1/2"×54mil

Environmental info (that day average): Temperature: 77F, Humidity: 43%

Test protocol: Cyclic-CUREE, reference displacement: 1.988in.

Test results

Maximum +load:1160plf

Maximum +load: 4640lbf

Net lateral displacement at top of wall at Maximum +load: 2.917in.

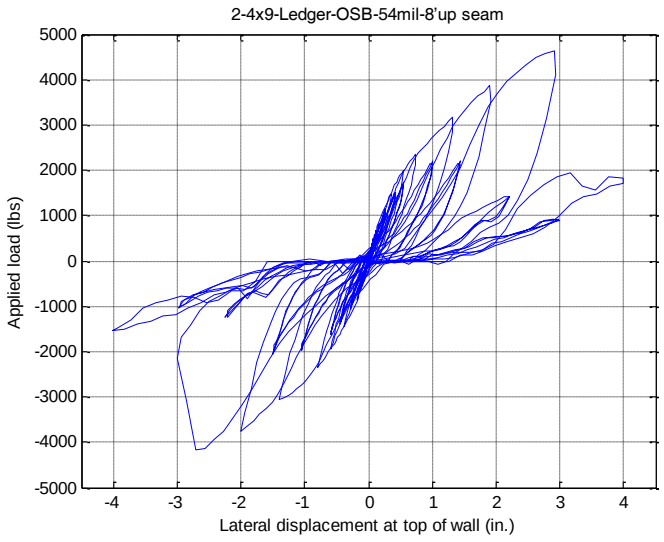
Maximum -load: -1044plf

Maximum -load: -4179lbs

Net lateral displacement at top of wall at Maximum -load: -2.714 in.

Average maximum load: 1102plf

Average net displacement: 2.815in.



Observed Failure Mode: Failure occurred along the horizontal panel seam at 8' height with Fasteners tilted and then pulled through the OSB.

Front side

Back side

Bottom (North)

Bottom (South)

Bottom fastener (South)

Bottom fasteners (North)

Horizontal Seam

Strap

Wall bracing

Test Label 3-4x9-Ledger-OSB-gyp-54mil-8'up seam Test Date:Nov.3, 2011

Specimen Configuration

Shear walls, back to back studs 600S162-54mil(50ksi), Track: 600T150-54mil(50ksi), Simpson S/HDU6 hold downs, ledger:1200T200-97mil(50ksi)

Wall dimensions: 4 ft. ×9ft. Loading type: Cyclic Ledger: Yes

Front sheathing: OSB Rated sheathing: APA 24/16 exposure 1 OSB Thickness:7/16"

Back sheathing: Gypsum board.

Fastener: Back to back studs: #10×1" Hex washer head Fastener spacing:12in.

Track to stud: #10×3/4" flat head

Hold downs: #14×1"Hex washer head Quantity: 12

OSB to stud: #8×1-15/16" flat head Fastener spacing: 6 in.

Clip to cold rolled channel: #8-3/4" flat head

Gypsum to stud: #6-x1-5/8"flat head

Field studs: 600S162-54mil (50ksi) Horizontal seam location: 8'up Vertical seam location: No

Strap: 1-1/2"-54mil

Wall bracing: Clip: 1-1/2"×1-1/2"×54mil Cold rolled channel: 1-1/2"×54mil

Environmental info (that day average): Temperature: 77F, Humidity: 43%

Test protocol: Cyclic-CUREE, reference displacement: 2.4in (40circles).

Test results

Maximum +load:1265plf

Maximum +load: 5060lbf

Net lateral displacement at top of wall at Maximum +load: 2.871 in.

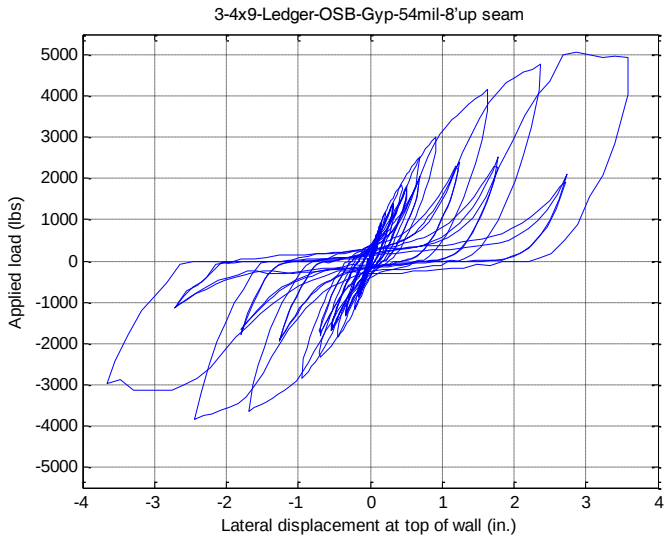
Maximum -load: -957.5plf

Maximum -load: -3830lbs

Net lateral displacement at top of wall at Maximum -load: -2.435 in.

Average maximum load: 1111.3plf

Average net displacement: 2.653in.



Observed Failure Mode: Fasteners on north chord stud all pulled through OSB, the screw hole was enlarged on the gypsum board.

Back side

Front side

Gypsum board

Fasteners in the gypsum board

OSB failure

Bottom (North)

Bottom (South)

Strap

Horizontal seam

Bottom fasteners (South)

Bottom fasteners (North)

Gypsum board after test

Hold down (South)

Hold down (North)

Wall bracing

Test Label 4-4x9- OSB-54mil-8'up seam Test Date: Nov.7, 2011

Specimen Configuration

Shear walls, back to back studs 600S162-54mil(50ksi), Track: 600T150-54mil(50ksi), Simpson S/HDU6 hold downs, ledger:1200T200-97mil(50ksi)

Wall dimensions: 4 ft. ×9ft. Loading type: Cyclic Ledger: No

Front sheathing: OSB Rated sheathing: APA 24/16 exposure 1 OSB Thickness: 7/16"

Back sheathing: Bare

Fastener: Back to back studs: #10×1" Hex washer head Fastener spacing:12in.

Track to stud: #10×3/4" flat head .

Hold downs: #14×1"Hex washer head Quantity: 12

OSB to stud: #8×1-15/16" flat head Fastener spacing:6 in.

Clip to cold rolled channel: #8-3/4" flat head

Gypsum to stud: N/A

Field studs: 600S162-54mil (50ksi) Horizontal seam location: 8'up Vertical seam location: No

Strap: 1-1/2"-54mil

Wall bracing: Clip: 1-1/2"×1-1/2"×54mil Cold rolled channel: 1-1/2"×54mil

Environmental info (that day average): Temperature: 77F, Humidity: 43%

Test protocol: Cyclic-CUREE, reference displacement: 1.988in.

Test results

Maximum +load:1047plf

Maximum +load: 4186lbf

Net lateral displacement at top of wall at Maximum +load: 2.877 in.

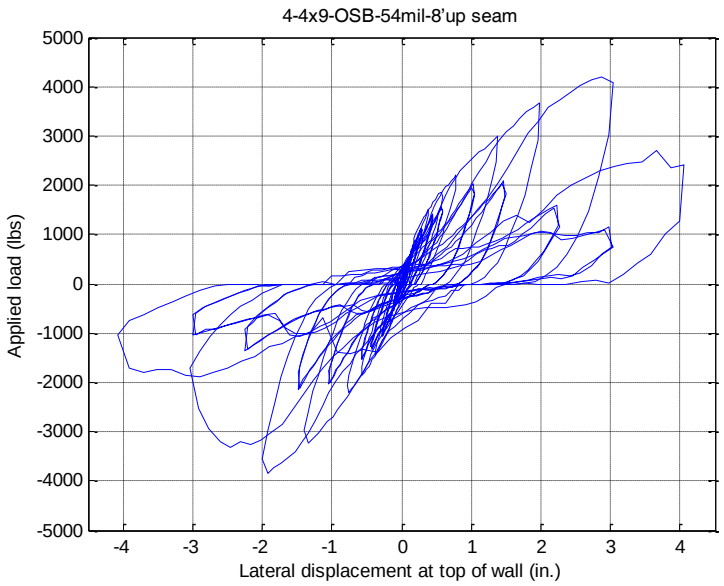
Maximum -load: -962.7plf

Maximum -load: -3851lbs

Net lateral displacement at top of wall at Maximum -load: -1.925 in.

Average maximum load: 1004.9plf

Average net displacement: 2.401in.



Observed Failure Mode: Fasteners in the seam location pulled through OSB.

Front side

Back side

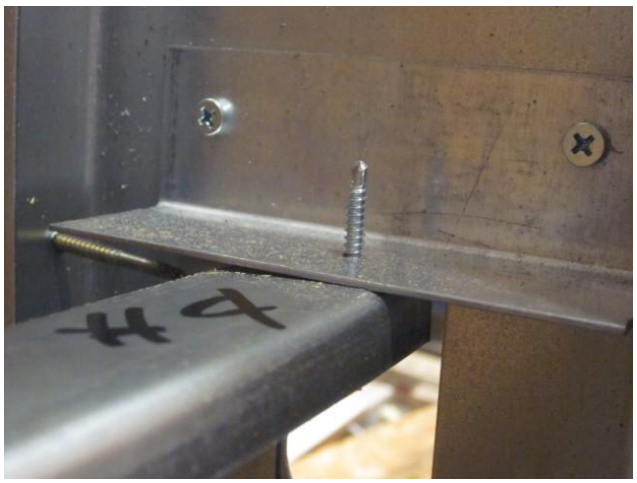
Bottom (North)

Bottom (South)

Strap

Seam

Wall bracing



Clip with CRC at chord stud

Bottom fasteners (South)

Bottom fasteners (North)

Hold down (north)

Hold down (south)

Test Label 5-4x9-Ledger- OSB-54mil-7'up seam Test Date: Nov.10, 2011

Specimen Configuration

Shear walls, back to back studs 600S162-54mil(50ksi), Track: 600T150-54mil(50ksi), Simpson S/HDU6 hold downs, ledger:1200T200-97mil(50ksi)

Wall dimensions: 4 ft. ×9ft. Loading type: Cyclic Ledger: Yes

Front sheathing: OSB Rated sheathing: APA 24/16 exposure 1 OSB Thickness:7/16"

Back sheathing: Bare.

Fastener: Back to back studs: #10×1" Hex washer head Fastener spacing: 12in.

Track to stud: #10×3/4" flat head .

Hold downs: #14×1"Hex washer head Quantity: 12

OSB to stud: #8×1-15/16" flat head Fastener spacing: 6 in.

Clip to cold rolled channel: #8-3/4" flat head

Gypsum to stud: N/A

Field studs: 600S162-54mil (50ksi) Horizontal seam location7'up Vertical seam location: No

Strap: 1-1/2"-54mil

Wall bracing: Clip: 1-1/2"×1-1/2"×54mil Cold rolled channel:1-1/2"×54mil

Environmental info (that day average): Temperature: 77F, Humidity: 43%

Test protocol: Cyclic-CUREE, reference displacement: 1.988in.

Test results

Maximum +load:1023plf

Maximum +load: 4093lbf

Net lateral displacement at top of wall at Maximum +load: 2.826 in.

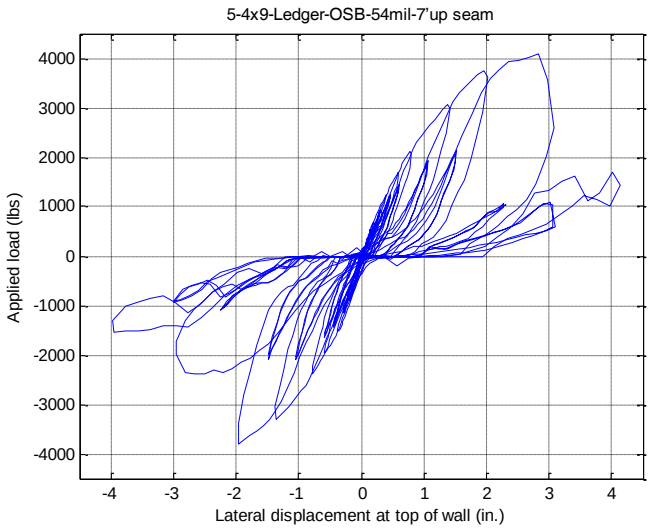
Maximum -load: -950.2plf

Maximum -load: -3801lbs

Net lateral displacement at top of wall at Maximum -load: -1.960 in.

Average maximum load: 986.88plf

Average net displacement: 2.393in.



Observed Failure Mode: Failure occurred at the bottom of the OSB, fasteners tilted and then pulled through the OSB.

Front side

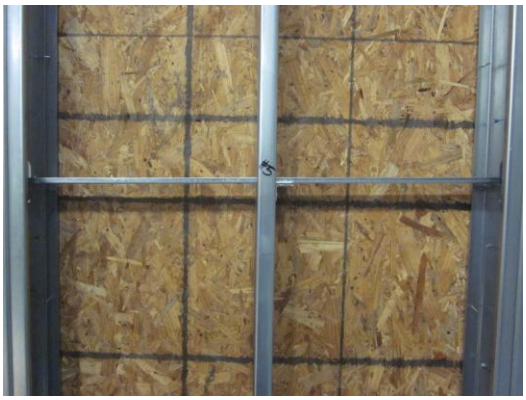
Back side

North side bottom

South side bottom

Seam location

Strap



Wall bracing

Connection

Hold down (North)

Hold down (South)

Bottom

OSB failure (North)

OSB failure (South)

Test Label 6-4x9-OSB-54mil-7'up seam Test Date: Nov.10, 2011

Specimen Configuration

Shear walls, back to back studs 600S162-54mil(50ksi), Track: 600T150-54mil(50ksi), Simpson S/HDU6 hold downs, ledger:1200T200-97mil(50ksi)

Wall dimensions: 4 ft. ×9ft. Loading type: Cyclic Ledger: No

Front sheathing: OSB Rated sheathing: APA 24/16 exposure 1 OSB Thickness: 7/16"

Back sheathing: Bare.

Fastener: Back to back studs: #10×1" Hex washer head Fastener spacing: 12in.

Track to stud: #10×3/4" flat head .

Hold downs: #14×1"Hex washer head Quantity: 12

OSB to stud: #8×1"-15/16" flat head Fastener spacing: 6 in.

Clip to cold rolled channel: #8-3/4" flat head

Gypsum to stud: N/A

Field studs: 600S162-54mil (50ksi) Horizontal seam location: 7'up Vertical seam location: No

Strap: 1-1/2"-54mil

Wall bracing: Clip: 1-1/2"×1-1/2"×54-mil Cold rolled channel: 1-1/2"×54-mil

Environmental info (that day average): Temperature: 75F, Humidity: 43%

Test protocol: Cyclic-CUREE, reference displacement: 1.988in.

Test results

Maximum +load:1232plf

Maximum +load: 4927lbf

Net lateral displacement at top of wall at Maximum +load: 2.783 in.

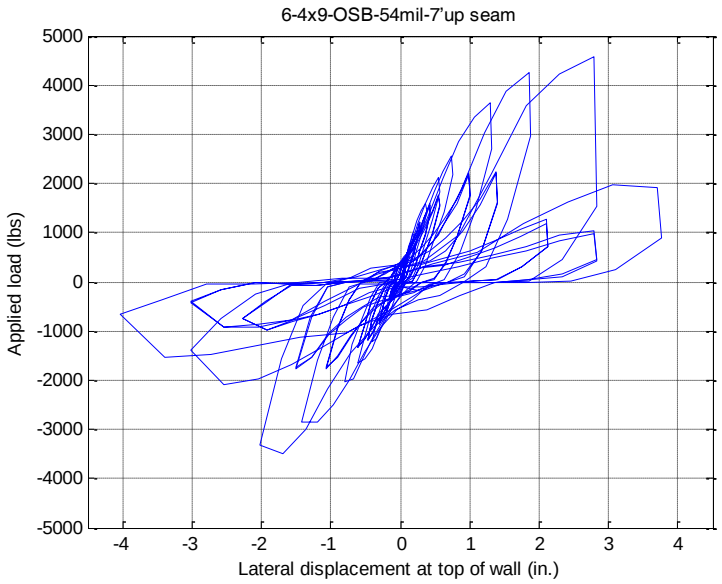
Maximum -load: -830.1plf

Maximum -load: -3321lbs

Net lateral displacement at top of wall at Maximum -load: -1.692 in.

Average maximum load: 1031plf

Average net displacement: 2.238in.



(This curve is from the actuator, not load cell)

Observed Failure Mode: Fasteners at chord studs 2'up and bottom pulled through OSB, bottom fasteners tilted observed.

Front side

Back side

North side bottom

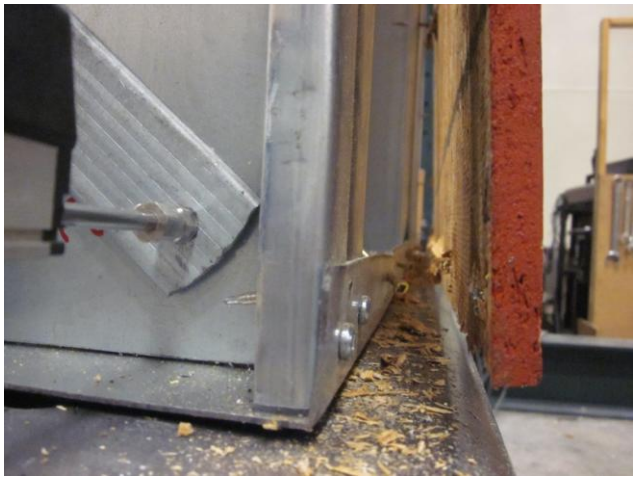
South side bottom

Seam location

Strap

Wall bracing

Connection



Bottom

Hold down (North)

Hold down (South)

Fasteners at the bottom (1)

Fasteners at the bottom (2)

Bottom failure

Test Label 7-4x9- OSB-54mil-1'over-8'up seam Test Date: Nov.17, 2011

Specimen Configuration

Shear walls, back to back studs 600S162-54mil(50ksi), Track: 600T150-54mil(50ksi), Simpson S/HDU6 hold downs, ledger:1200T200-97mil(50ksi)

Wall dimensions: 4 ft. ×9ft. Loading type: Cyclic Ledger: No

Front sheathing: OSB Rated sheathing: APA 24/16 exposure 1 OSB Thickness: 7/16"

Back sheathing: Bare.

Fastener: Back to back studs: #10×1" Hex washer head Fastener spacing:12in.

Track to stud: #10×3/4" flat head .

Hold downs: #14×1"Hex washer head Quantity: 12

OSB to stud: #8×1-15/16" flat head Fastener spacing: 6 in.

Clip to cold rolled channel: #8-3/4" flat head

Gypsum to stud: N/A

Field studs: 600S162-54mil (50ksi) Additional filed stud 1'over: 600S162-54mil (33ksi)

Horizontal Seam location: 7'up

Vertical seam location: 1'over

Strap: 1-1/2"-54mil

Wall bracing: Clip: 1-1/2"×1-1/2"×54mil Cold rolled channel: 1-1/2"×54mil

Environmental info (that day average): Temperature: 77F, Humidity:43%

Test protocol: Cyclic-CUREE, reference displacement: 1.988in.

Test results

Maximum +load:875.9plf

Maximum +load: 3504lbf

Net lateral displacement at top of wall at Maximum +load: 2.550 in.

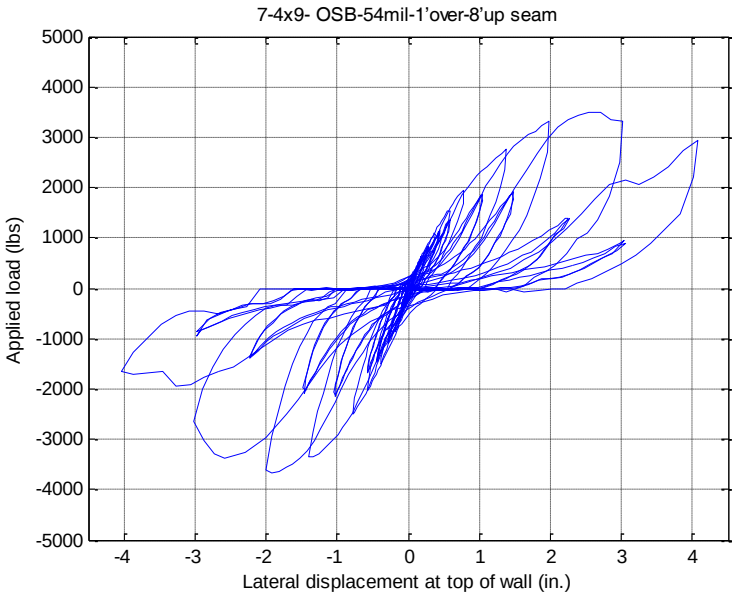
Maximum -load: -918.2plf

Maximum -load: -3672.7lbs

Net lateral displacement at top of wall at Maximum -load: -1.911 in.

Average maximum load: 897.1plf

Average net displacement: 2.230in.



Observed Failure Mode: Failure occurred at vertical and horizontal seam, fasteners tilted and pulled through the OSB.

Front side

Back side

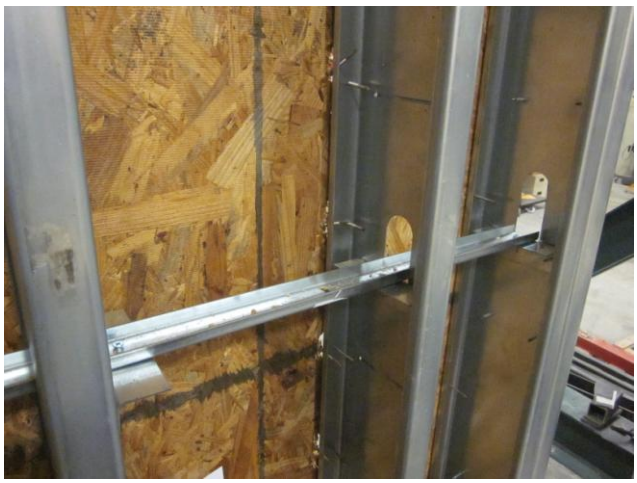
South side bottom

North side bottom

Seam location

Strap (1)

Strap (2)



Wall bracing

Hold down (North)

Hold down (South)

Bottom

Bottom fastener (1)

Bottom fastener (2)

Bottom Fasteners (3)

Additional stud connection with bottom track

Additional stud connection with top track

Additional stud at vertical seam (Bottom)

Test Label 8-4x9-OSB-54mil-2'over-8'up seam Test Date: Nov.17, 2011

Specimen Configuration

Shear walls, back to back studs 600S162-54mil(50ksi), Track: 600T150-54mil(50ksi), Simpson S/HDU6 hold downs, ledger:1200T200-97mil(50ksi)

Wall dimensions: 4 ft. ×9ft. Loading type: Cyclic Ledger: No

Front sheathing: OSB Rated sheathing: APA 24/16 exposure 1 OSB Thickness: 7/16"

Back sheathing: Bare.

Fastener: Back to back studs: #10×1" Hex washer head Fastener spacing:12in.

Track to stud: #10×3/4" flat head .

Hold downs: #14×1"Hex washer head Quantity: 12

OSB to stud: #8×1-15/16" flat head Fastener spacing: 6 in.

Clip to cold rolled channel: #8-3/4" flat head

Gypsum to stud: N/A

Field studs: 600S162-54mil (50ksi) Additional filed stud 2'over: 600S162-54mil(50ksi)

Horizontal Seam location: 8'up

Vertical seam location: 2'over

Strap: 1-1/2"-54mil

Wall bracing: Clip: 1-1/2"×1-1/2"×54-mil Cold rolled channel:1-1/2"×54-mil

Environmental info (that day average): Temperature: 75F, Humidity: 53%

Test protocol: Cyclic-CUREE, reference displacement: 1.988in.

Test results

Maximum +load:1036plf

Maximum +load: 4144lbf

Net lateral displacement at top of wall at Maximum +load: 3.655 in.

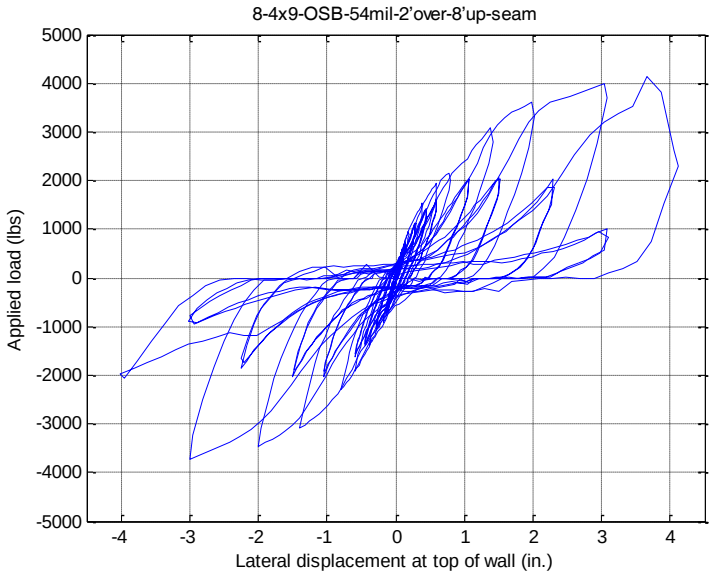
Maximum -load: -928.8plf

Maximum -load: -3715lbs

Net lateral displacement at top of wall at Maximum -load: -3.003 in.

Average maximum load: 982.4plf

Average net displacement: 3.329in.



Observed Failure Mode: Fasteners at vertical seam (without additional stud) pulled through OSB.

Front side

Back side

South side bottom

North side bottom

Seam location

Strap

Hold down (North)

Hold down (South)

Bottom

Bottom fastener (1)

Bottom fastener (2)

Bottom fastener (3)

Test Label 9-4x9- OSB-54mil-2'over-8'up seam Test Date:Nov.18, 2011

Specimen Configuration

Shear walls, back to back studs 600S162-54mil(50ksi), Track: 600T150-54mil(50ksi), Simpson S/HDU6 hold downs, ledger:1200T200-97mil(50ksi)

Wall dimensions: 4 ft. ×9ft. Loading type: Cyclic Ledger: No

Front sheathing: OSB Rated sheathing: APA 24/16 exposure 1 OSB Thickness: 7/16"

Back sheathing: Bare.

Fastener: Back to back studs: #10×1" Hex washer head Fastener spacing: 12in.

Track to stud: #10×3/4" flat head .

Hold downs: #14×1"Hex washer head Quantity: 12

OSB to stud: #8×1-15/16" flat head Fastener spacing: 6 in.

Clip to cold rolled channel: #8-3/4" flat head

Gypsum to stud: N/A

Field studs: 600S162-54mil (50ksi) Horizontal seam location: 8'up Vertical seam location: 2'over

Strap: 1-1/2"-54mil

Wall bracing: Clip: 1-1/2"×1-1/2"×54-mil Cold rolled channel: 1-1/2"×54-mil

Environmental info (that day average): Temperature: 75F, Humidity:56%

Test protocol: Cyclic-CUREE, reference displacement: 1.988in.

Test results

Maximum +load:920.8plf

Maximum +load: 3683lbf

Net lateral displacement at top of wall at Maximum +load: 4.201 in.

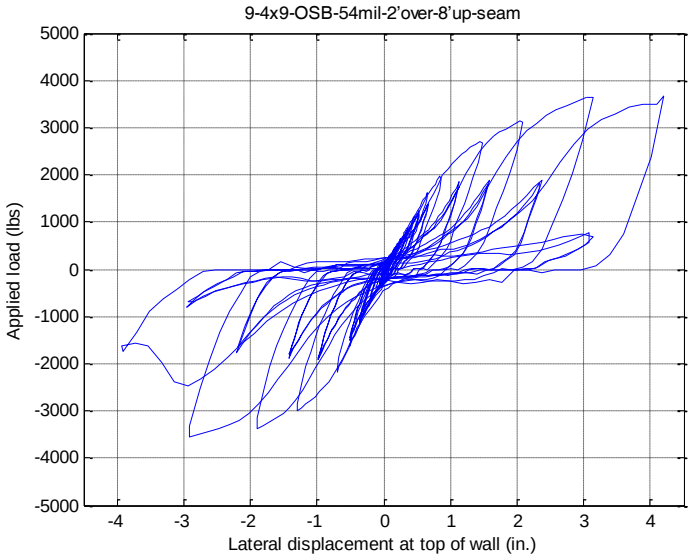
Maximum -load: -890.3plf

Maximum -load: -3561lbs

Net lateral displacement at top of wall at Maximum -load: -2.918 in.

Average maximum load: 905.5plf

Average net displacement: 3.559in.



Observed Failure Mode: Fasteners at one side vertical seam pulled through OSB.

Front side

Back side

South side bottom

North side bottom

Strap

Wall bracing

Hold down (North)

Hold down (South)

Test Label 10-4x9- OSB-54mil-4.5'over-4.5'up seam Test Date: Nov.18, 2011

Specimen Configuration

Shear walls, back to back studs 600S162-54mil(50ksi), Track: 600T150-54mil(50ksi), Simpson S/HDU6 hold downs, ledger:1200T200-97mil(50ksi)

Wall dimensions: 4 ft. ×9ft. Loading type: Cyclic Ledger: No

Front sheathing: OSB Rated sheathing: APA 24/16 exposure 1 OSB Thickness: 7/16''

Back sheathing: Bare.

Fastener: Back to back studs: #10×1'' Hex washer head Fastener spacing:12in.

Track to stud: #10×3/4'' flat head .

Hold downs: #14×1''Hex washer head Quantity: 12

OSB to stud: #8×1-15/16'' flat head Fastener spacing: 6 in.

Clip to cold rolled channel: #8-3/4'' flat head

Gypsum to stud: N/A

Field studs: 600S162-54mil (50ksi) Horizontal seam location: 4.5'up Vertical seam location: 2'over

Strap: 1-1/2''-54mil

Wall bracing: Clip: 1-1/2"×1-1/2"×54-mil Cold rolled channel: 1-1/2"×54-mil

Environmental info (that day average): Temperature: 75F, Humidity:53%

Test protocol: Cyclic-CUREE, reference displacement: 1.988in.

Test results

Maximum +load:950.8plf

Maximum +load: 3803lbf

Net lateral displacement at top of wall at Maximum +load: 2.911 in.

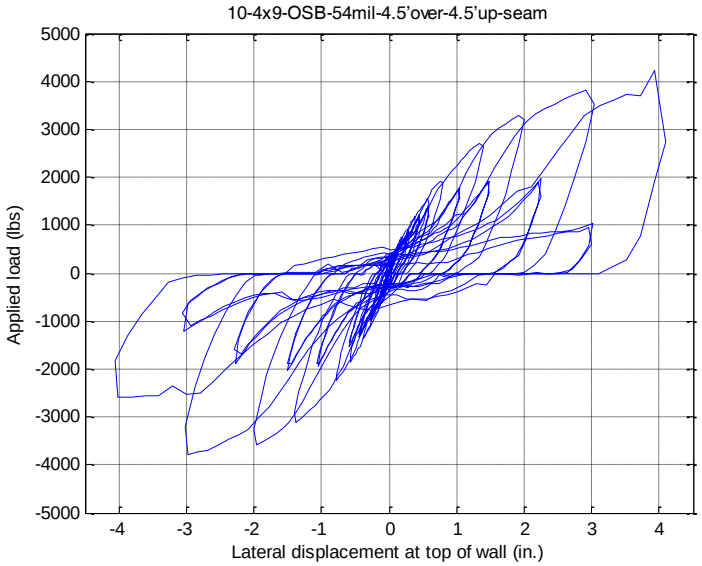
Maximum -load: -949.8plf

Maximum -load: -3799lbs

Net lateral displacement at top of wall at Maximum -load: -2.978 in.

Average maximum load: 950.2plf

Average net displacement: 2.945in.



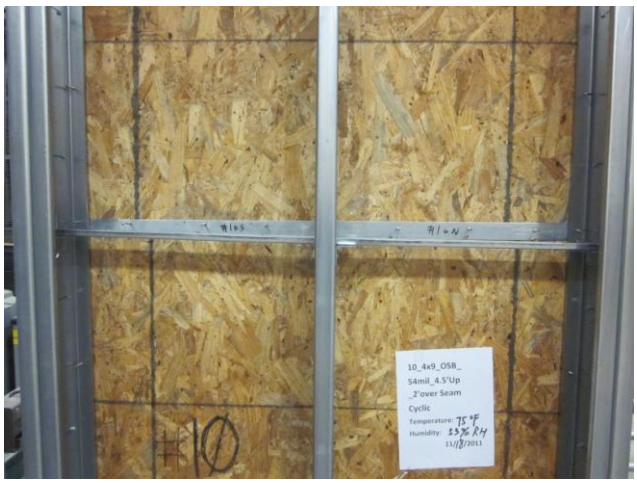
Observed Failure Mode: Fasteners at vertical seam location (south bottom part of OSB) pulled through OSB.

Front side

Back side

South side bottom

North side bottom



Strap

Hold down (North)

Hold down (South)

Bottom

Fastener at the bottom (1)

Fastener at the bottom (2)

Seam connection

Test Label 11a-4x9-54mil Test Date: OCT.28, 2011

Specimen Configuration

Shear walls, back to back studs 600S162-54mil(50ksi), Track: 600T150-54mil(50ksi), Simpson S/HDU6 hold downs, ledger:1200T200-97mil(50ksi)

Wall dimensions: 8 ft. ×9ft. Loading type: K Ledger: No

Front sheathing: Bare Rated sheathing: N/A Back sheathing: Bare.

Fastener: Back to back studs: #10×1'' Hex washer head Fastener spacing: 12in.

Track to stud: #10×3/4'' flat head .

Hold downs: #14×1''Hex washer head Quantity:12

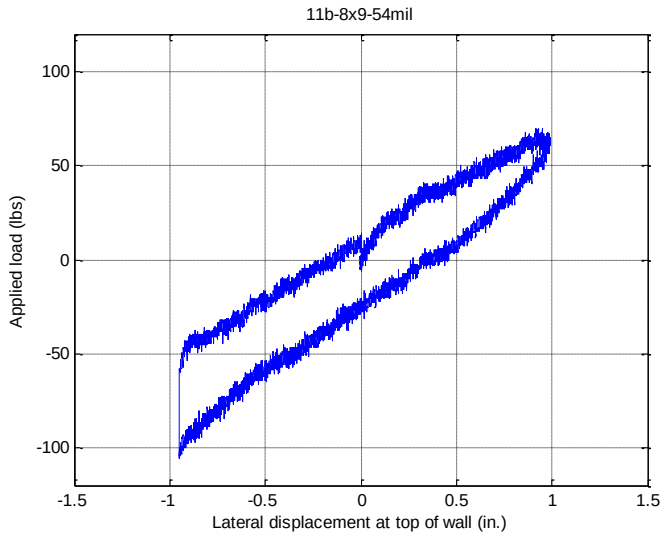
Field studs: 600S162-54mil (50ksi) Wall bracing: Clip: 1-1/2"×1-1/2"×54mil

Cold rolled channel: 1-1/2"×54mil

Test results

load: 87.75lbs

Net lateral displacement at top of frame: 0.932in.



Stiffness of the frame: 94.15lbs/in.

Test Label 11b-8x9-ledger-54mil Test Date: OCT.29, 2011

Specimen Configuration

Shear walls, back to back studs 600S162-54mil(50ksi), Track: 600T150-54mil(50ksi), Simpson S/HDU6 hold downs, ledger: 1200T200-97mil(50ksi)

Wall dimensions: 8 ft. ×9ft. Loading type: K Ledger: Yes

Front sheathing: Bare Rated sheathing: N/A Back sheathing: Bare.

Fastener: Back to back studs: #10×1'' Hex washer head Fastener spacing: 12in.

Track to stud: #10×3/4'' flat head .

Hold downs: #14×1''Hex washer head Quantity: 12

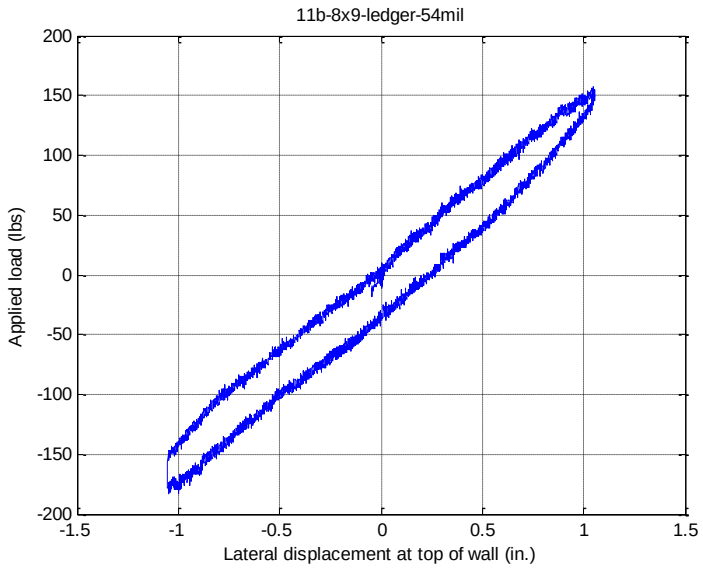
Field studs: 600S162-54mil (50ksi)

Wall bracing: Clip: 1-1/2"×1-1/2"×54mil Cold rolled channel: 1-1/2"×54mil

Test results

Average load:170.3lbs

Net lateral displacement at top of frame: 1.022in.



Stiffness of the frame: 166.6lbs/in.

Test Label 11M-8x9-Ledger–OSB-54mil-8'up seam Test Date: Nov.30, 2011

Specimen Configuration

Shear walls, back to back studs 600S162-54mil(50ksi), Track: 600T150-54mil(50ksi), Simpson S/HDU6 hold downs, ledger:1200T200-97mil(50ksi)

Wall dimensions: 8 ft. ×9ft. Loading type: Monotonic Ledger: Yes

Front sheathing: OSB Rated sheathing: APA 24/16 exposure 1 OSB Thickness: 7/16"

Back sheathing: Bare.

Fastener: Back to back studs: #10×1" Hex washer head Fastener spacing:12in.

Track to stud: #10×3/4" flat head .

Hold downs: #14×1"Hex washer head Quantity:12

OSB to stud: #8×1-15/16" flat head Fastener spacing:6 in.

Fasteners at OSB Bottom spacing: 12in.

Clip to cold rolled channel: #8-3/4" flat head

Gypsum to stud: N/A

Field studs: 600S162-54mil (50ksi) Horizontal seam location: 8'up

Strap: 1-1/2"-54mil

Wall bracing: Clip: 1-1/2"×1-1/2"×54mil Cold rolled channel: 1-1/2"×54mil

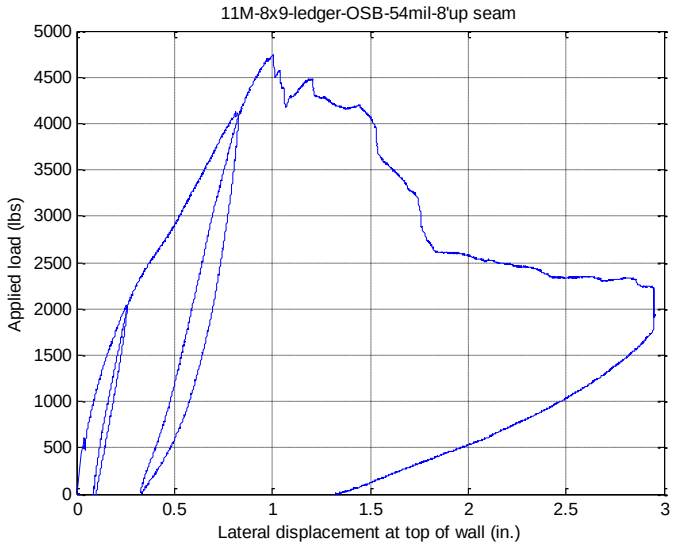
Environmental info (that day average): Temperature: 75F, Humidity: 58%

Test results

Maximum +load:593.1plf

Maximum +load: 4745lbf

Net lateral displacement at top of wall at Maximum +load: 1.004in.

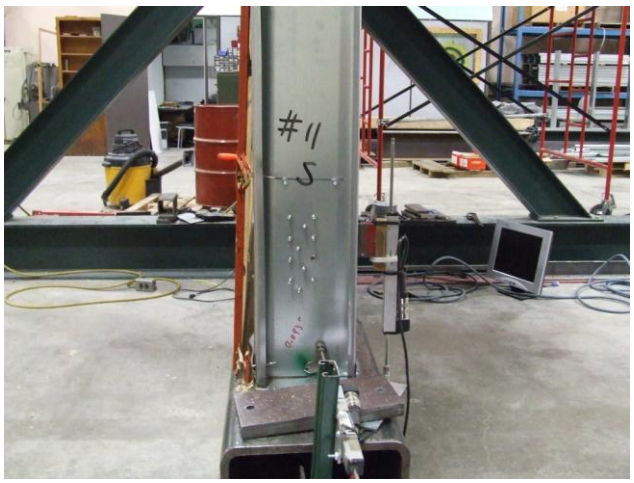


Observed Failure Mode: Failure at bottom OSB.(Bottom fastener spacing 12in. which is supposed to be 6in.).

Front side

Back side

Bottom (North)



Bottom (South)

Missing fasteners at the bottom

Test Label 11c-8x9-Ledger–OSB-54mil-8’up seam Test Date: Dec.2, 2011

Specimen Configuration

Shear walls, back to back studs 600S162-54mil(50ksi), Track: 600T150-54mil(50ksi), Simpson S/HDU6 hold downs, ledger:1200T200-97mil(50ksi)

Wall dimensions: 8 ft. ×9ft. Loading type: Monotonic Ledger: Yes

Front sheathing: OSB Rated sheathing: APA 24/16 exposure 1 OSB Thickness: 7/16”

Back sheathing: Bare.

Fastener: Back to back studs: #10×1” Hex washer head Fastener spacing:12in.

Track to stud: #10×3/4” flat head .

Hold downs: #14×1”Hex washer head Quantity: 12

OSB to stud: #8×1-15/16” flat head Fastener spacing: 6 in.

Clip to cold rolled channel: #8-3/4” flat head

Gypsum to stud: N/A

Field studs: 600S162-54mil (33ksi) Horizontal seam location: 8’up

Strap: 1-1/2”-54mil

Wall bracing: Clip: 1-1/2"×1-1/2"×54mil Cold rolled channel: 1-1/2"×54mil

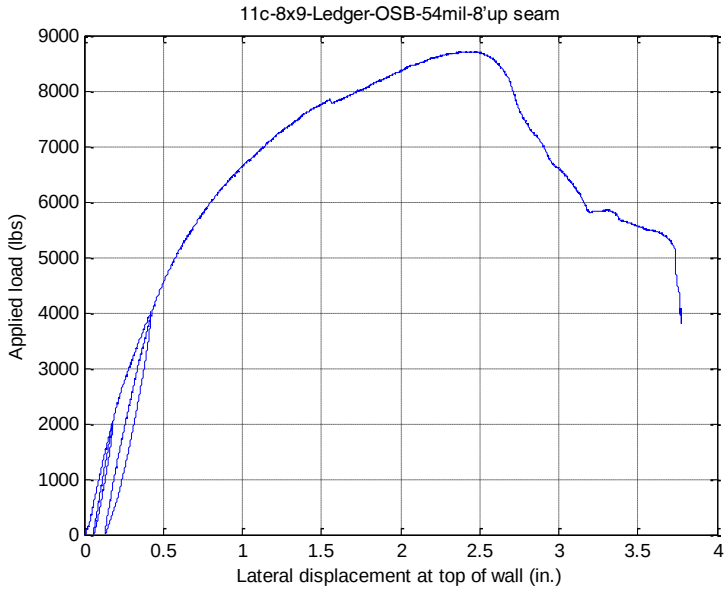
Environmental info (that day average): Temperature: 75F, Humidity: 58%

Test results

Maximum +load:1088.5plf

Maximum +load:8708.3lbf

Net lateral displacement at top of wall at Maximum +load: 2.4182 in.



Observed Failure Mode: Failure occurred at vertical seam with wood bearing failure and fasteners pulled through OSB. .

Front side

Back side

Bottom (North)

Bottom (South)

Bottom fasteners (1)

Bottom fasteners (2)

Bottom fasteners (3)

Bottom fasteners (4)

Test Label 12-8x9-Ledger- OSB-54mil-8'up seam Test Date: Dec.7, 2011

Specimen Configuration

Shear walls, back to back studs 600S162-54mil(50ksi), Track: 600T150-54mil(50ksi), Simpson S/HDU6 hold downs, ledger:1200T200-97mil(50ksi)

Wall dimensions: 8 ft. ×9ft. Loading type: Cyclic Ledger: Yes

Front sheathing: OSB Rated sheathing: APA 24/16 exposure 1 OSB Thickness: 7/16"

Back sheathing: Bare.

Fastener: Back to back studs: #10×1" Hex washer head Fastener spacing: 12in.

Track to stud: #10×3/4" flat head .

Hold downs: #14×1"Hex washer head Quantity: 12

OSB to stud: #8×1-15/16" flat head Fastener spacing: 6 in.

Clip to cold rolled channel : #8-3/4" flat head

Gypsum to stud: N/A

Field studs: 600S162-54mil (50ksi) Horizontal seam location: 8'up

Strap: 1-1/2"-54mil

Wall bracing: Clip: 1-1/2"×1-1/2"×54mil Cold rolled channel: 1-1/2"×54mil

Environmental info (that day average): Temperature:75F, Humidity:53%

Test protocol: Cyclic-CUREE, reference displacement: 1.752in.

Test results

Maximum +load:1256.1plf

Maximum +load: 10049lbf

Net lateral displacement at top of wall at Maximum +load: 2.2672 in.

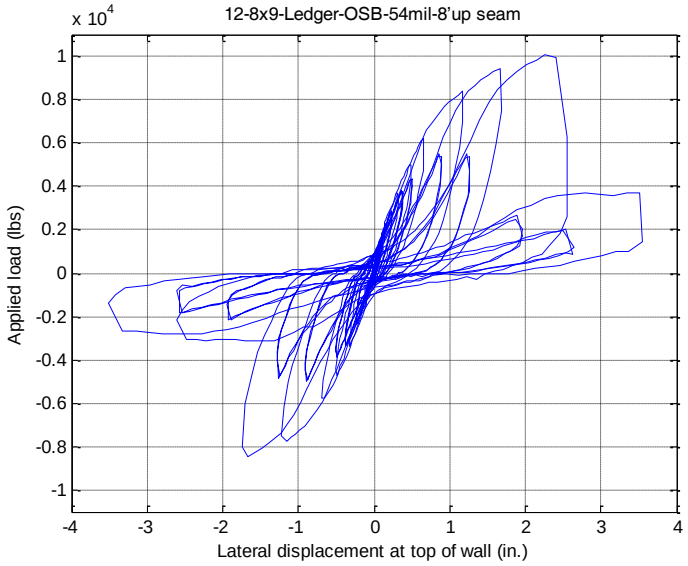
Maximum -load: -1055.4plf

Maximum -load: -8443.1lbs

Net lateral displacement at top of wall at Maximum -load: -1.6616 in.

Average maximum load: 1155.7plf

Average net displacement: 1.9644in.



Observed Failure Mode: Fasteners at chord studs from bottom up to 2' up pulled through OSB.

Front side

Back side

South side bottom

North side bottom

Strap

Clip and CRC Connection at field stud

Hold down (North)

Hold down (South)

Bottom fastener (1)

Bottom fastener (2)

Bottom fastener (3)

Bottom fastener (4)

Test Label 13-8x9-Ledger- OSB-gyp-54mil-8'up seam

Test Date:Dec.7, 2011

Specimen Configuration

Shear walls, back to back studs 600S162-54mil(50ksi),Track:600T150-54mil(50ksi), Simpson S/HDU6 hold downs, ledger:1200T200-97mil(50ksi)

Wall dimensions: 8ft. ×9ft. Loading type: Cyclic Ledger: Yes

Front sheathing: OSB Rated sheathing: APA 24/16 exposure 1 OSB Thickness: 7/16"

Back sheathing: Gypsum.

Fastener: Back to back studs: #10×1" Hex washer head Fastener spacing: 12in.

Track to stud: #10×3/4" flat head .

Hold downs: #14×1"Hex washer head Quantity: 12

OSB to stud: #8×1-15/16" flat head Fastener spacing:6 in.

Clip to cold rolled channel: #8-3/4" flat head

Gypsum to stud: #6×1-5/8"

Field studs: 600S162-54mil (50ksi) Horizontal seam location: 8'up

Strap: 1-1/2"-54mil

Wall bracing: Clip: 1-1/2"×1-1/2"×54mil Cold rolled channel:1-1/2"×54mil

Environmental info (that day average): Temperature: 75F, Humidity: 58%

Test protocol: Cyclic-CUREE, reference displacement: 1.752in.

Test results

Maximum +load:1327plf

Maximum +load: 10616lbf

Net lateral displacement at top of wall at Maximum +load: 2.1989 in.

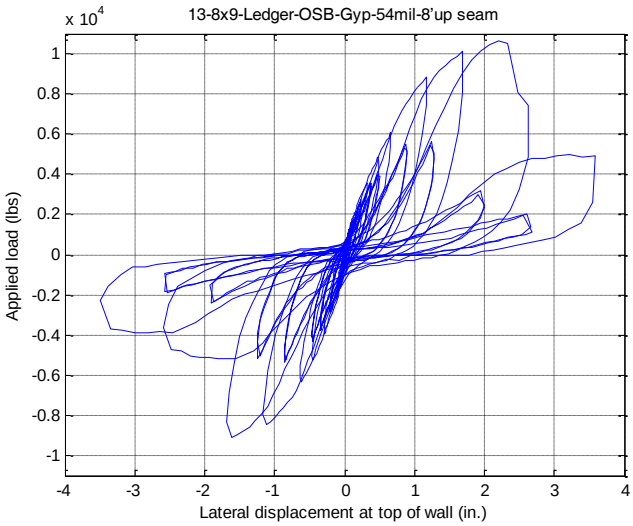
Maximum -load: -1137.9plf

Maximum -load:- 9103.1lbs

Net lateral displacement at top of wall at Maximum -load: -1.6178 in.

Average maximum load: 1232.4plf

Average net displacement:1.9084in.



Observed Failure Mode: Failure occurred at OSB bottom and gypsum board. Fasteners at gypsum board enlarge holes, major of fasteners pull through board. South side gypsum board already separated from the frame. OSB side, bottom fasteners at bottom and chord stud up to2' pulled through OSB.

Front side

Back side

North side bottom

South side bottom

Seam location

Strap

Hold down (North) Hold down (South)

Bottom fastener (1)

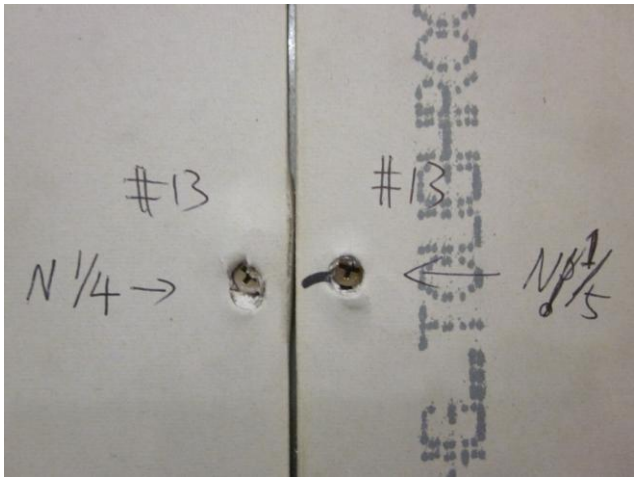
Bottom fastener (2)

Bottom fastener (3)

Bottom fastener (4)

Middle field stud

Gypsum boards



Vertical seam fasteners

Fasteners at top

Corner fastener (1)

Corner fastener (2)

Corner fastener (3)

North side

South side

Test Label 14-8x9- OSB-54mil-8'up seam Test Date: Dec.8, 2011

Specimen Configuration

Shear walls, back to back studs 600S162-54mil(50ksi), Track:600T150-54mil(50ksi), Simpson S/HDU6 hold downs, ledger:1200T200-97mil(50ksi)

Wall dimensions: 8ft. ×9ft. Loading type: Cyclic Ledger: No

Front sheathing: OSB Rated sheathing: APA 24/16 exposure 1 OSB Thickness: 7/16"

Back sheathing: Bare.

Fastener: Back to back studs: #10×1" Hex washer head Fastener spacing:12in.

Track to stud: #10×3/4" flat head .

Hold downs: #14×1"Hex washer head Quantity: 12

OSB to stud: #8×1-15/16" flat head Fastener spacing: 6 in.

Clip to cold rolled channel: #8-3/4" flat head

Gypsum to stud: #6×1-5/8"

Field studs: 600S162-54mil (50ksi) Horizontal seam location: 8'up

Strap: 1-1/2"-54mil

Wall bracing: Clip: 1-1/2"×1-1/2"×54mil Cold rolled channel: 1-1/2"×54mil

Environmental info (that day average): Temperature: 75F, Humidity: 53%

Test protocol: Cyclic-CUREE, reference displacement: 1.752in.

Test results

Maximum +load:1055.5plf

Maximum +load: 8444lbf

Net lateral displacement at top of wall at Maximum +load:2.220in.

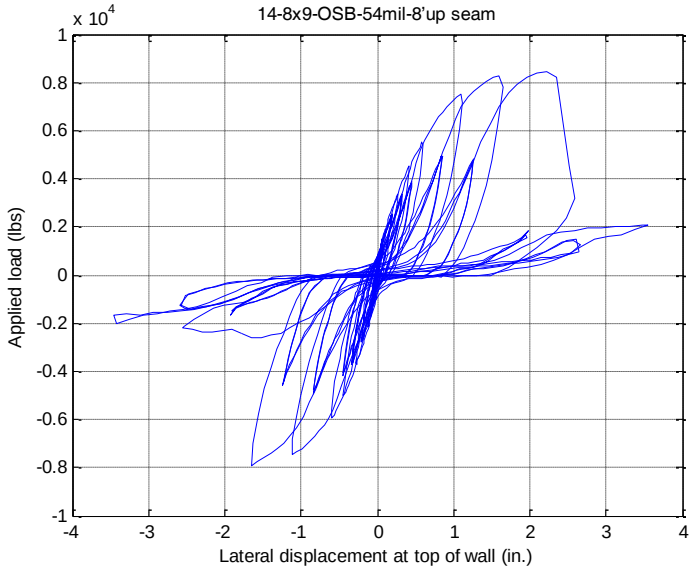
Maximum -load: -990.14plf

Maximum -load: -7921.1lbs

Net lateral displacement at top of wall at Maximum -load: -1.656 in.

Average maximum load: 1022.8plf

Average net displacement: 1.938in.

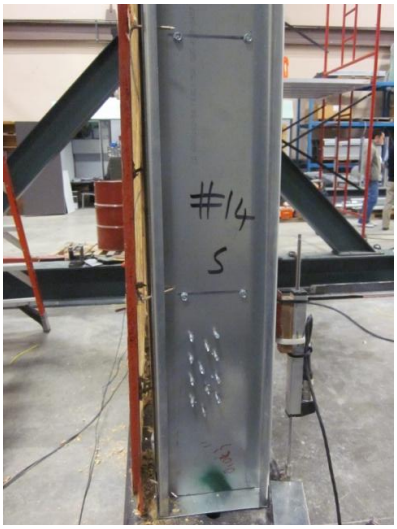


Observed Failure Mode: Failure occur at bottom fasteners pull through OSB, fasteners at chord studs up to 3'pull through and several wood bearing failures observed.

Front side

Back side

North side bottom



South side bottom

Seam location

Strap

Wall bracing

Connection

Bottom

Hold down (North)

Hold down (South)

Bottom fasteners (1)

Bottom fasteners (2)

Bottom fasteners (3)

Bottom fasteners (4)

Middle field stud fasteners

Test Label 15-8x9- OSB-33mil-8'up seam Test Date: Dec.9, 2011

Specimen Configuration

Shear walls, back to back studs 600S162-54mil(50ksi), Track:600T150-54mil(50ksi), Simpson S/HDU6 hold downs, ledger:1200T200-97mil(50ksi)

Wall dimensions: 8 ft. ×9ft. Loading type: Cyclic Ledger: Yes

Front sheathing: OSB Rated sheathing: APA 24/16 exposure 1 OSB Thickness: 7/16"

Back sheathing: Bare.

Fastener: Back to back studs: #10×1" Hex washer head Fastener spacing: 12in.

Track to stud: #10×3/4" flat head .

Hold downs: #14×1"Hex washer head Quantity: 12

OSB to stud: #8×1-15/16" flat head Fastener spacing: 6 in.

Clip to cold rolled channel: #8-3/4" flat head

Gypsum to stud: N/A

Field studs: 600S162-33mil (33ksi) Horizontal seam location: 8'up

Strap: 1-1/2"-54mil

Wall bracing: Clip: 1-1/2"×1-1/2"×54mil Cold rolled channel: 1-1/2"×54mil

Environmental info (that day average): Temperature: 75F, Humidity:53%

Test protocol: Cyclic-CUREE, reference displacement: 1.752in.

Test results

Maximum +load:883.01plf

Maximum +load: 7064.1lbf

Net lateral displacement at top of wall at Maximum +load: 1.616 in.

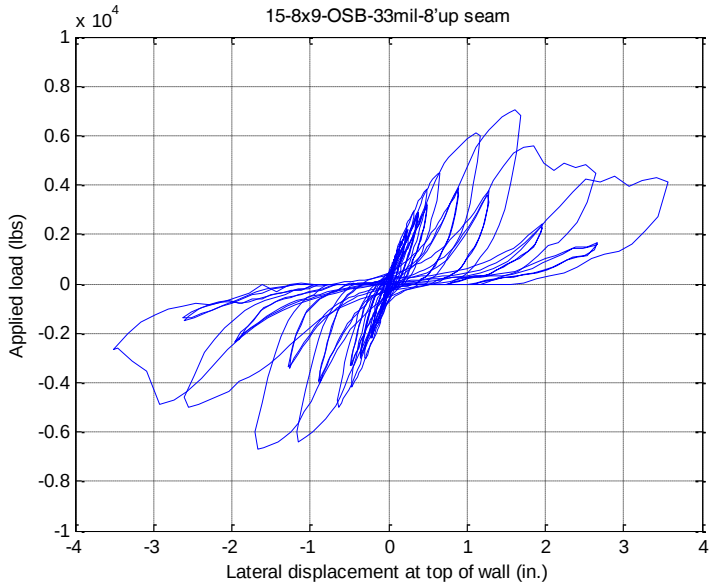
Maximum -load: -839plf

Maximum -load: -6712lbs

Net lateral displacement at top of wall at Maximum -load: -1.6743 in.

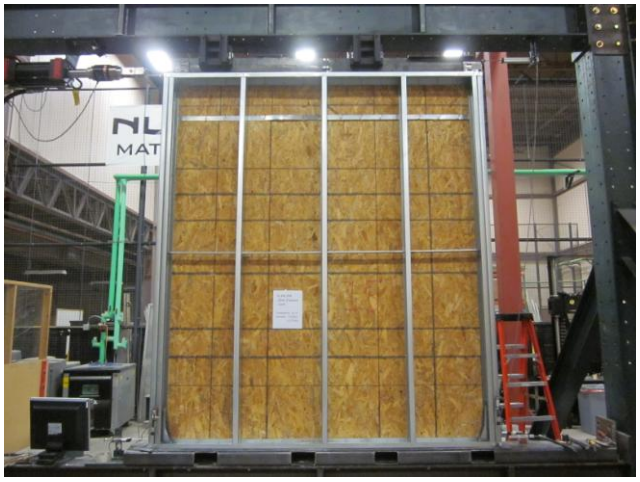
Average maximum load: 861plf

Average net displacement: 1.6447in.



Observed Failure Mode: Failure occurred at vertical and horizontal seam with fastener tilted and pulled through OSB.

Back side



Front side

South side bottom

North side bottom

Seam (1)

Seam (2)

Seam (3)

Hold down (North)

Hold down (South)

Bottom fasteners (1)

Bottom fasteners (2)

Bottom fasteners (3)

Bottom fasteners (4)

Fasteners at middle field stud

Bottom

Test Label 16-8x9-Ledger-54mil Test Date: Dec.13, 2011

Specimen Configuration

Shear walls, back to back studs 600S162-54mil(50ksi), Track: 600T150-54mil(50ksi), Simpson S/HDU6 hold downs, ledger:1200T200-97mil(50ksi)

Wall dimensions: 8 ft. ×9ft. Loading type: Cyclic Ledger: Yes

Front sheathing: Gypsum board. Rated sheathing: APA 24/16 exposure 1 Back sheathing: Bare

Fastener: Back to back studs: #10×1" Hex washer head Fastener spacing: 12in.

Track to stud: #10×3/4" flat head .

Hold downs: #14×1"Hex washer head Quantity:12

OSB to stud: N/A Fastener spacing: 6 in.

Clip to cold rolled channel: #8-3/4" flat head

Gypsum to stud: #6×1-5/8"

Field studs: 600S162-54mil (50ksi) Horizontal seam location: 8'up

Strap: 1-1/2"-54mil

Wall bracing: Clip: 1-1/2"×1-1/2"×54mil Cold rolled channel:1-1/2"×54mil

Environmental info (that day average): Temperature: 75F, Humidity: 58%

Test protocol: Cyclic-CUREE, reference displacement: 1.752in.

Test results

Maximum +load:258.8plf

Maximum +load: 2070.4lbf

Net lateral displacement at top of wall at Maximum +load: 1.22in.

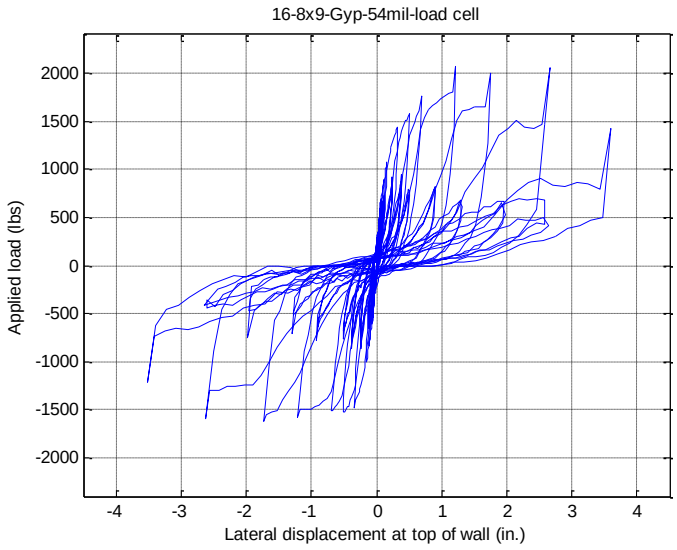
Maximum -load: -202.43plf

Maximum -load: -1619.44lbs

Net lateral displacement at top of wall at Maximum -load: -1.73 in.

Average maximum load: 230.62plf

Average net displacement: 1.47in.



Observed Failure Mode: Screw holes enlarged; fasteners pulled through gypsum board. Gypsum board at chord studs has already separated.

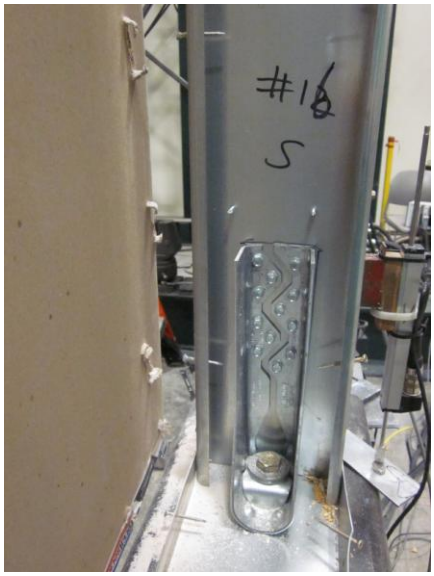
Front side

Back side

South side bottom

North side bottom

Hold down (North)



Hold down (South)

Bottom fasteners (1)

Bottom fasteners (2)

Bottom fasteners (3)

Bottom fasteners (4)

Fasteners at bottom

Back side

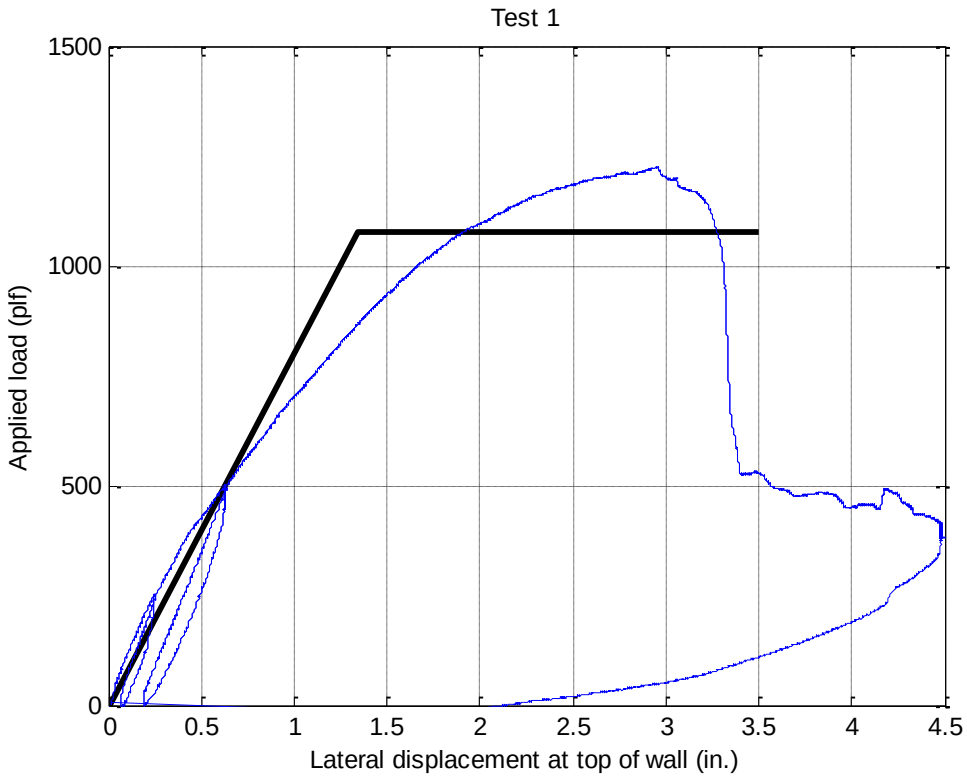
Appendix C EEEP and backbone curve plots

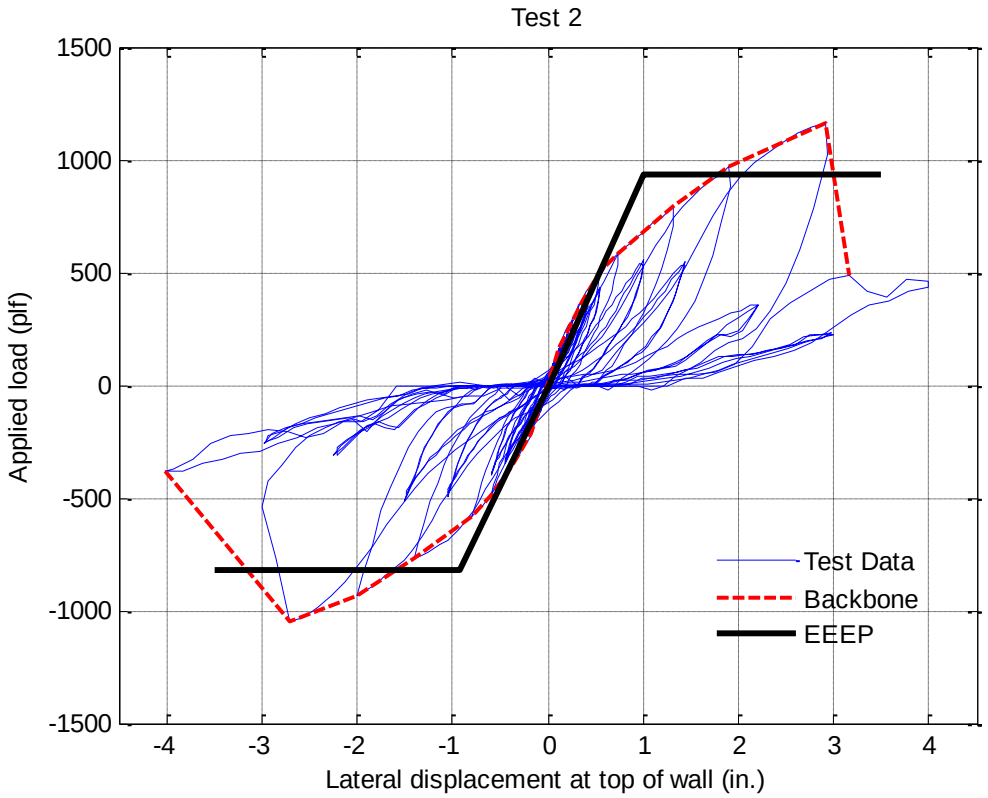
Test label	[1]P0.4u+ (plf.)	[2]Δ0.4u+ (in.)	[3]k+	[4]P0.8u+ (plf.)	[5]Δ0.8u+ (in.)	[6]Py+ (plf.)	[7]Ductility Ratio+	P0.4u- (plf.)	Δ0.4u- (in.)	k-	P0.8u- (plf.)	Δ0.8u- (in.)	Py- (plf.)	Ductility Ratio-	Avg. k	Avg. Ductility Factor
1c	489.20	0.61	801.70	978.40	3.16	1078.30	2.35	-	-	-	-	-	-	-	801.70	2.63
2	464.06	0.50	932.42	670.08	2.92	936.83	2.99	417.93	0.47	882.46	714.50	3.36	871.05	3.17	907.44	3.08
3	506.00	0.49	1028.88	1010.00	3.58	1082.30	3.40	383.01	0.35	1108.25	785.91	2.94	841.40	3.87	1068.57	3.64
4	418.59	0.47	888.91	837.17	3.32	864.14	3.63	385.06	0.42	923.40	832.06	2.46	812.84	2.94	906.15	3.28
5	409.39	0.56	729.87	818.77	3.23	889.55	3.41	380.12	0.37	1030.68	760.00	2.34	792.89	3.04	880.28	3.22
6	492.73	0.39	1276.83	915.84	2.88	1068.60	3.45	313.31	0.58	542.91	626.64	2.23	646.16	2.12	909.87	2.78
7	350.39	0.52	679.44	736.10	4.08	781.53	3.54	367.27	0.37	989.40	734.40	2.48	802.06	3.06	834.42	3.30
8	414.39	0.45	916.79	828.78	3.86	883.45	4.01	371.50	0.42	883.69	742.40	3.44	820.40	3.70	900.24	3.85
9	368.31	0.60	610.69	736.60	4.20	825.37	3.11	356.06	0.46	780.15	712.00	2.93	810.04	2.82	695.42	2.97
10	380.27	0.56	683.33	760.00	3.77	818.10	3.15	379.91	0.45	852.01	760.00	3.63	824.76	4.14	767.67	3.65
11c	434.40	0.36	1221.25	868.70	2.91	956.65	3.72	-	-	-	-	-	-	-	1221.25	4.04
12	502.43	0.35	1436.32	1004.80	2.61	1096.70	3.40	422.15	0.32	1324.20	844.00	1.84	916.71	2.66	1380.26	3.03
13	530.80	0.40	1324.01	1061.60	2.58	1166.90	2.93	455.15	0.26	1729.31	910.30	1.69	984.37	2.96	1526.66	2.95
14	422.20	0.27	1551.63	844.40	2.55	944.25	4.20	396.04	0.22	1767.25	745.52	1.66	868.44	3.37	1659.44	3.78
15	353.20	0.31	1147.88	701.06	1.85	737.36	2.88	335.60	0.26	1269.77	673.57	2.37	749.58	4.01	1208.82	3.44
16	103.55	0.10	1022.23	205.60	3.28	236.40	14.18	80.97	0.07	1098.66	161.60	3.34	190.54	19.25	1060.45	16.71

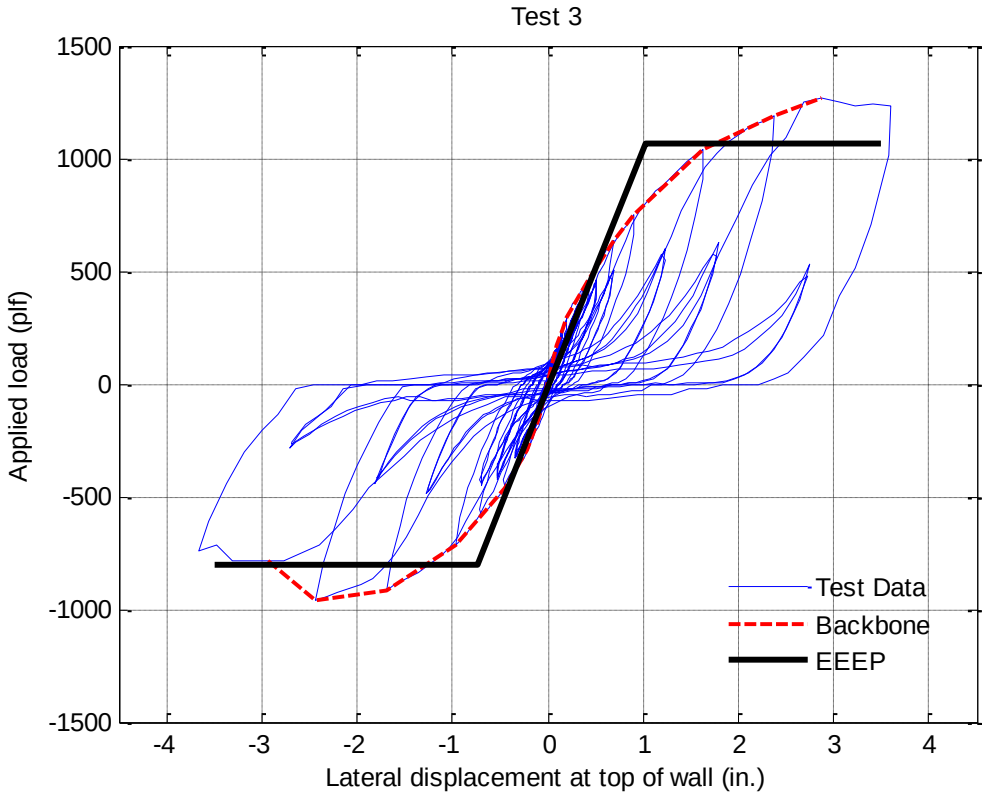
Note: [1]P0.4u+: 40% of positive peak load at backbone curve,[2]Δ0.4u+: corresponding displacement of P0.4u+ at backbone curve, [3]k+: initial stiffness([1]P0.4u+/[2]Δ0.4u+).

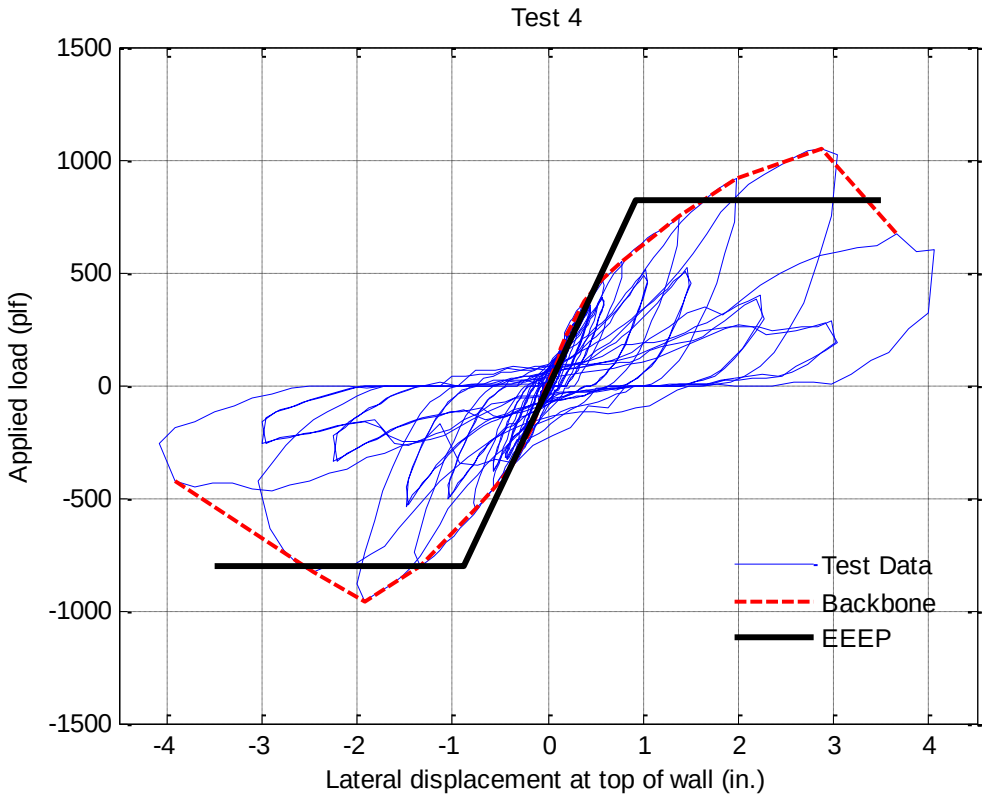
[4]P0.8u+: 80% of positive peak load at backbone curve,[5]Δ0.8u+: corresponding displacement of P0.8u+ at backbone curve.

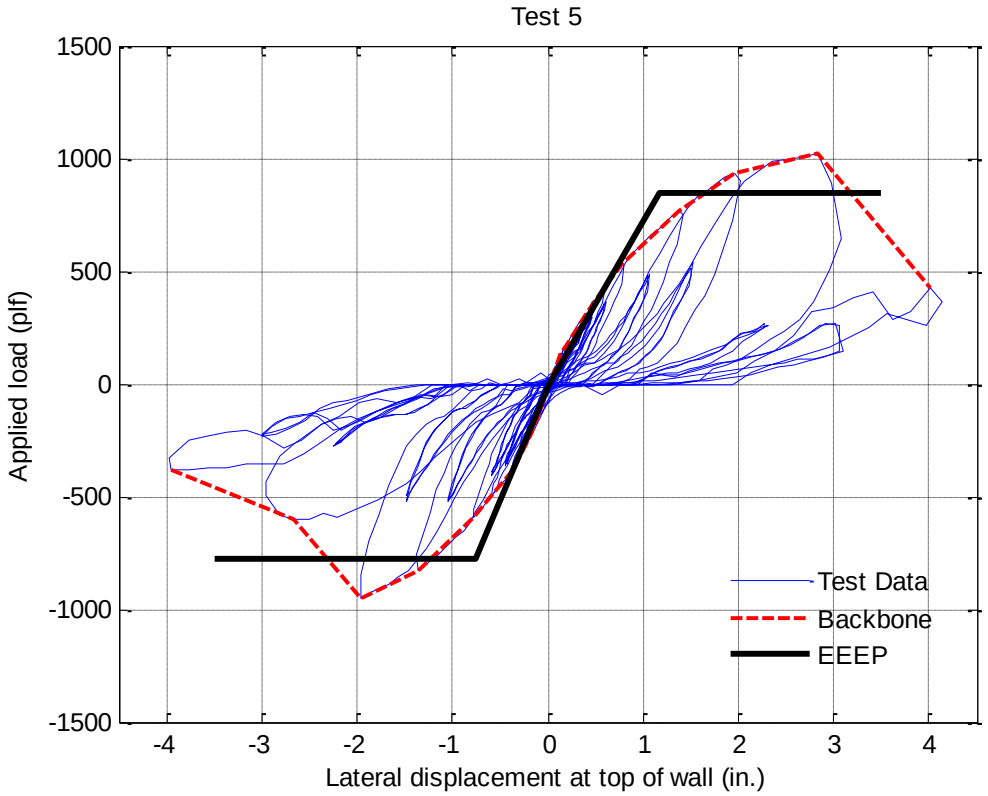
[6]Py+,[7]Ductility Ratio+: acording to ASTM E2126-11 to calculate yield load and ductility ratio.

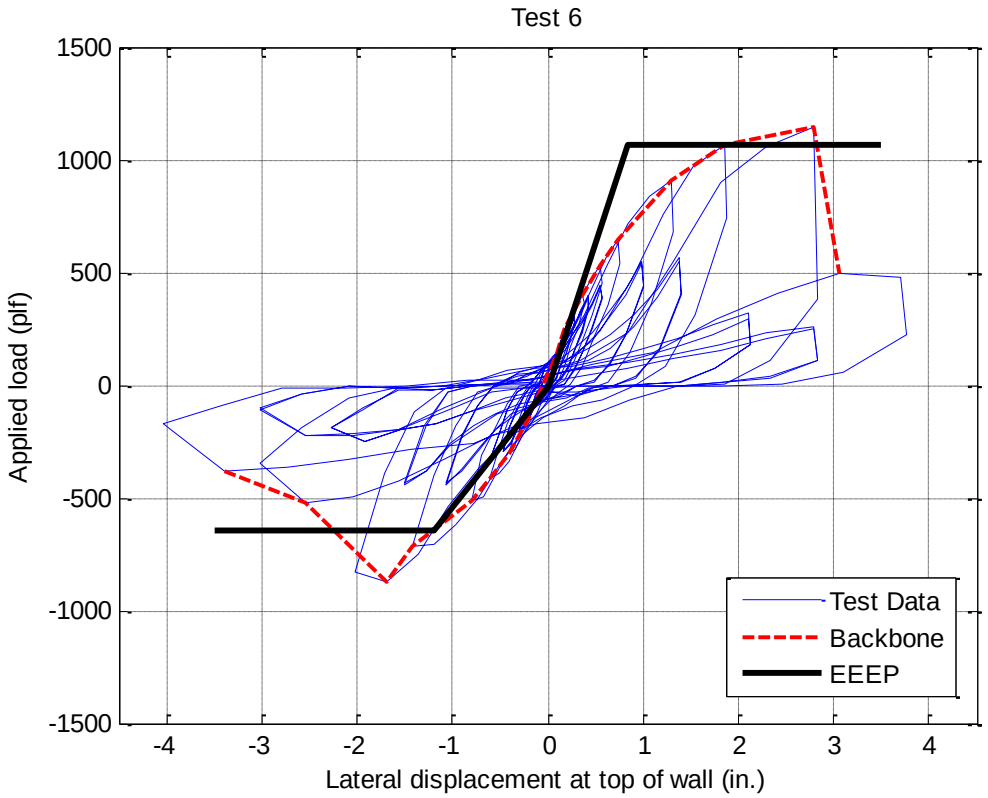

Test 1
1500
1000
500
0
Applied load (plf)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
Lateral displacement at top of wall (in.)

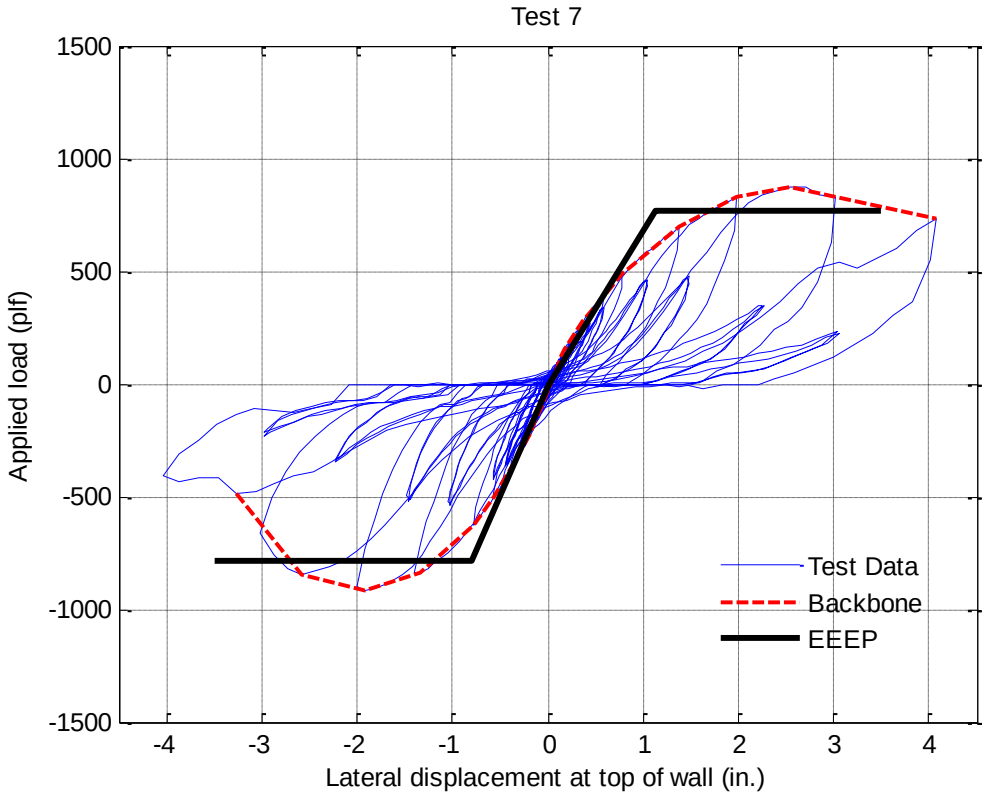

Test 2
1500
1000
500
0
-500
-1000
-1500
Applied load (plf)
-4
-3
-2
-1
0
1
2
3
4
Lateral displacement at top of wall (in.)
Test Data
Backbone
EEEP

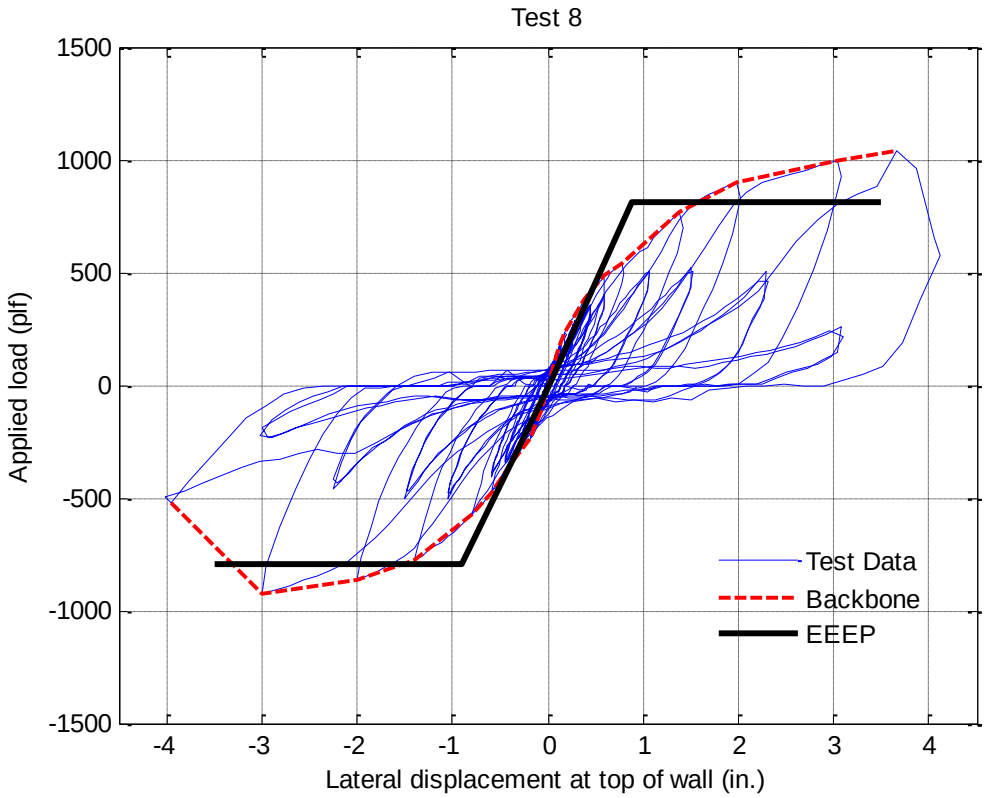

Test 3
1500
1000
500
0
-500
-1000
-1500
Applied load (plf)
-4
-3
-2
-1
0
1
2
3
4
Lateral displacement at top of wall (in.)
Test Data
Backbone
EEEP

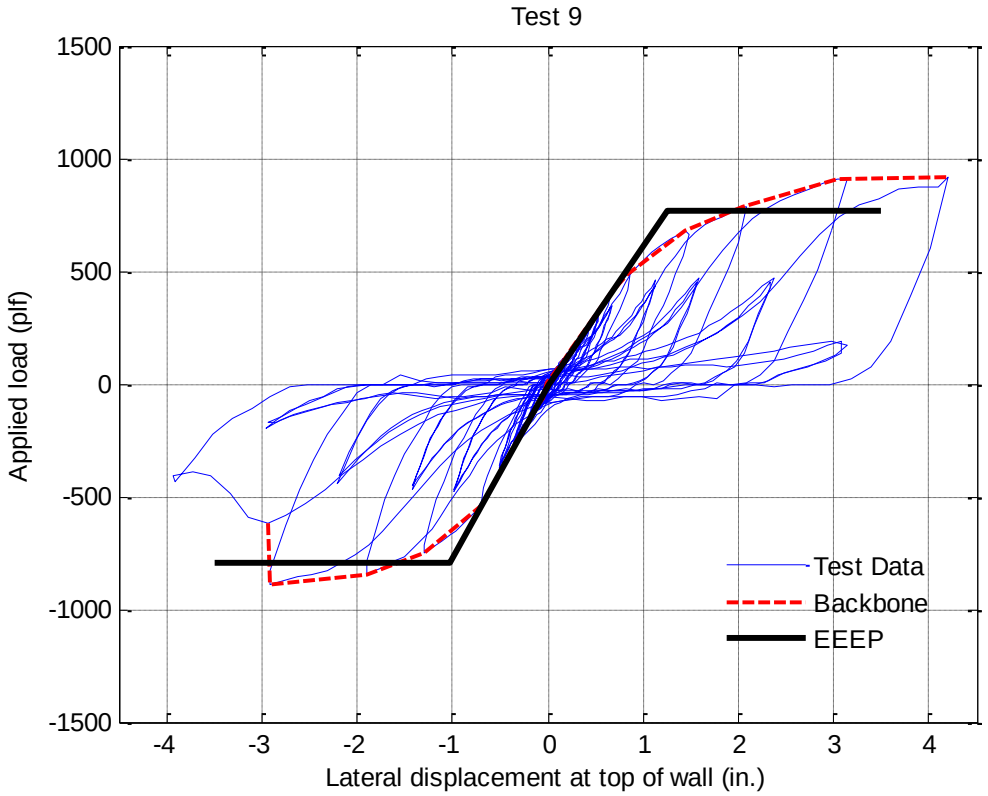

Test 4
1500
1000
500
0
-500
-1000
-1500
Applied load (plf)
-4
-3
-2
-1
0
1
2
3
4
Lateral displacement at top of wall (in.)
Test Data
Backbone
EEEP

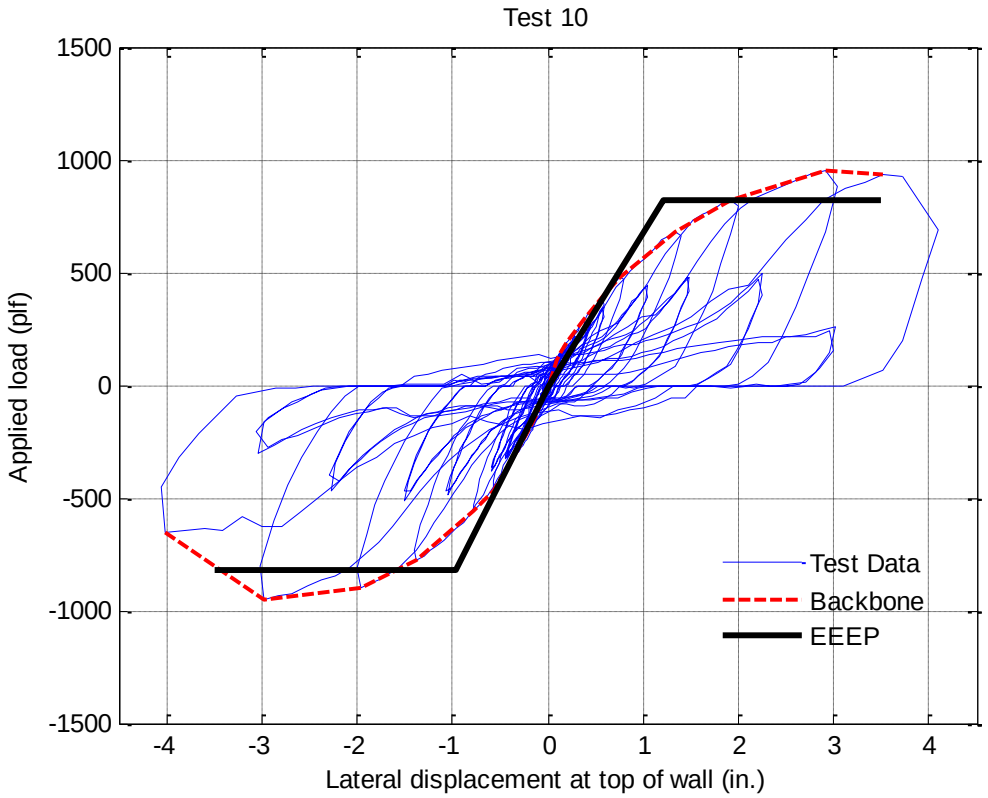

Test 5
1500
1000
500
0
-500
-1000
-1500
Applied load (plf)
-4
-3
-2
-1
0
1
2
3
4
Lateral displacement at top of wall (in.)
Test Data
Backbone
EEEP

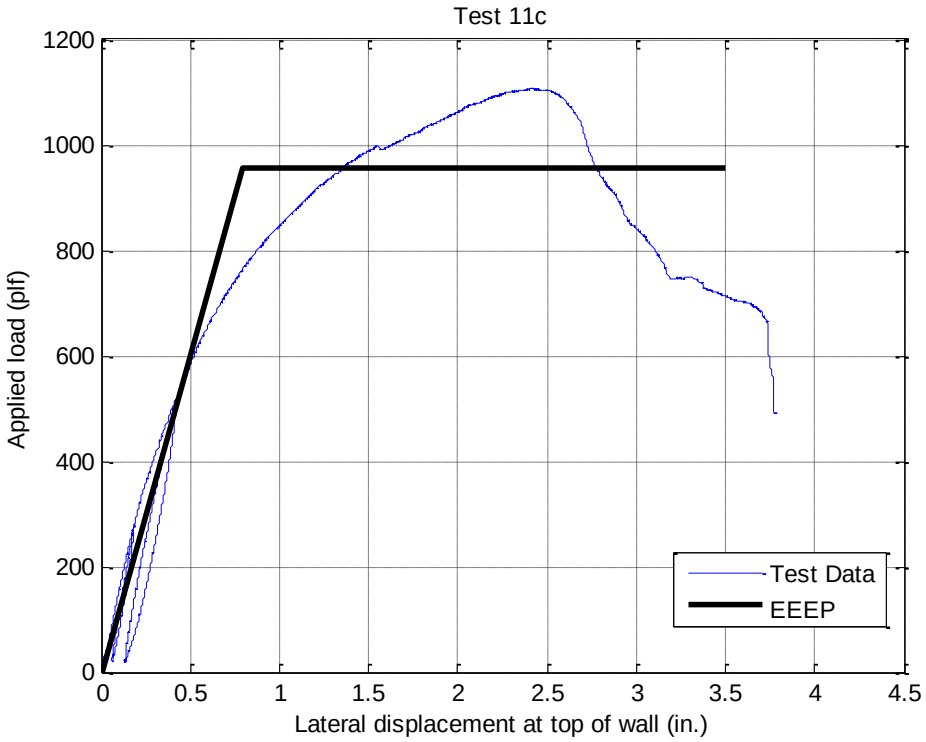

Test 6
1500
1000
500
0
-500
-1000
-1500
Applied load (plf)
-4
-3
-2
-1
0
1
2
3
4
Lateral displacement at top of wall (in.)
Test Data
Backbone
EEEP

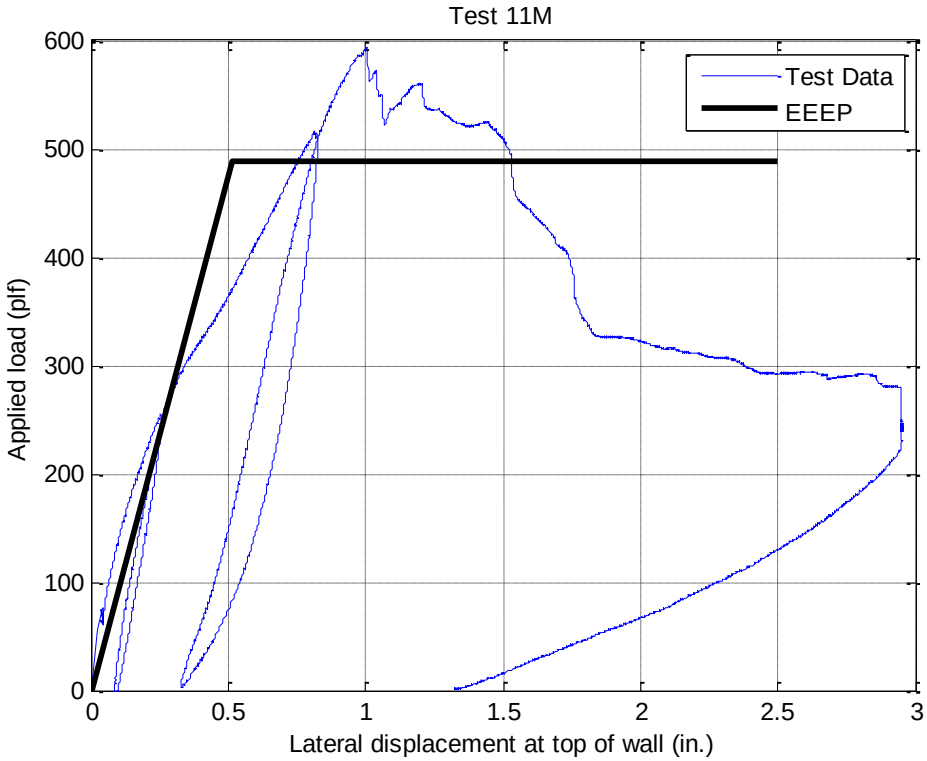

Test 7
1500
1000
500
0
-500
-1000
-1500
Applied load (plf)
-4
-3
-2
-1
0
1
2
3
4
Lateral displacement at top of wall (in.)
Test Data
Backbone
EEEP

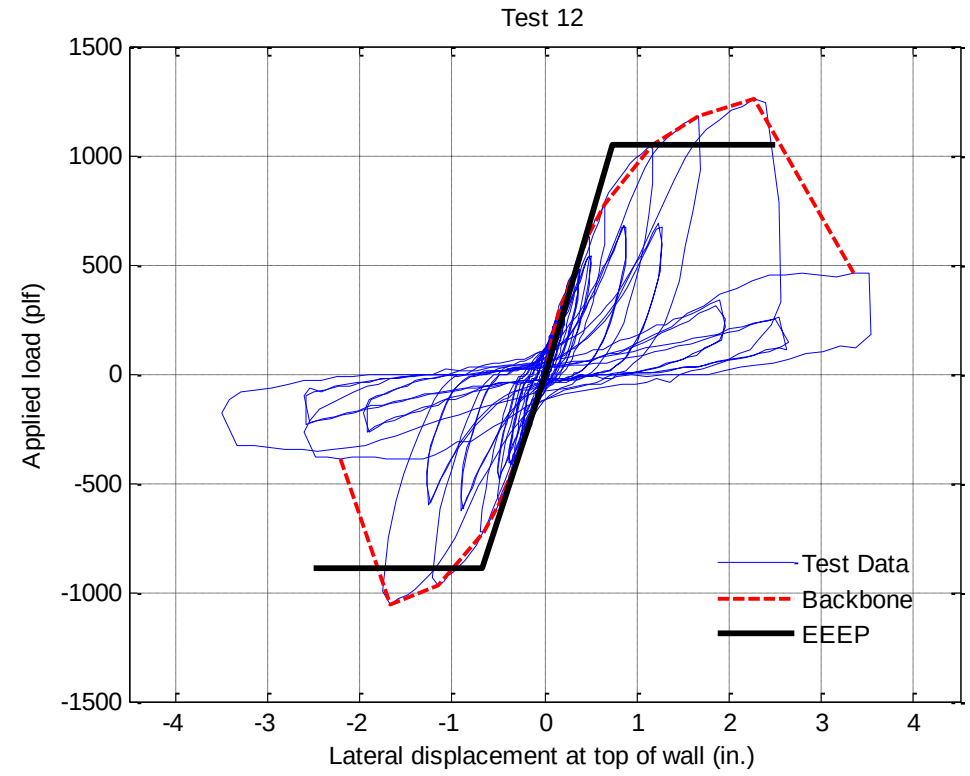

Test 8
1500
1000
500
0
-500
-1000
-1500
Applied load (plf)
-4
-3
-2
-1
0
1
2
3
4
Lateral displacement at top of wall (in.)
Test Data
Backbone
EEEP

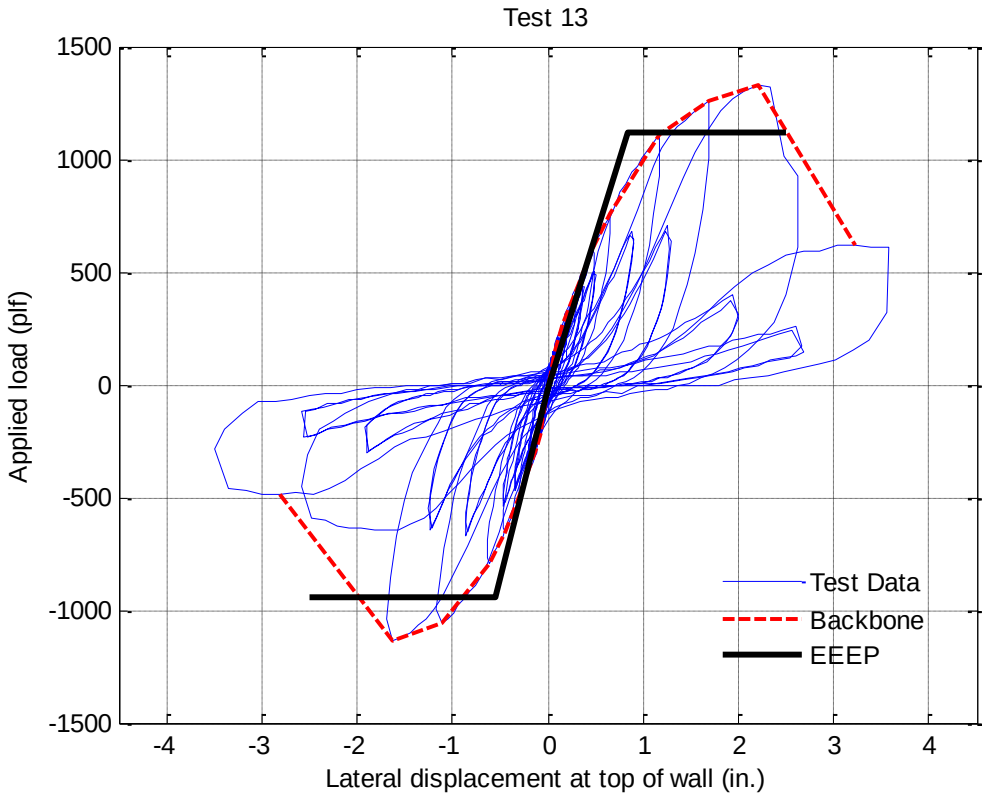

Test 9
1500
1000
500
0
-500
-1000
-1500
Applied load (plf)
-4
-3
-2
-1
0
1
2
3
4
Lateral displacement at top of wall (in.)
Test Data
Backbone
EEEP

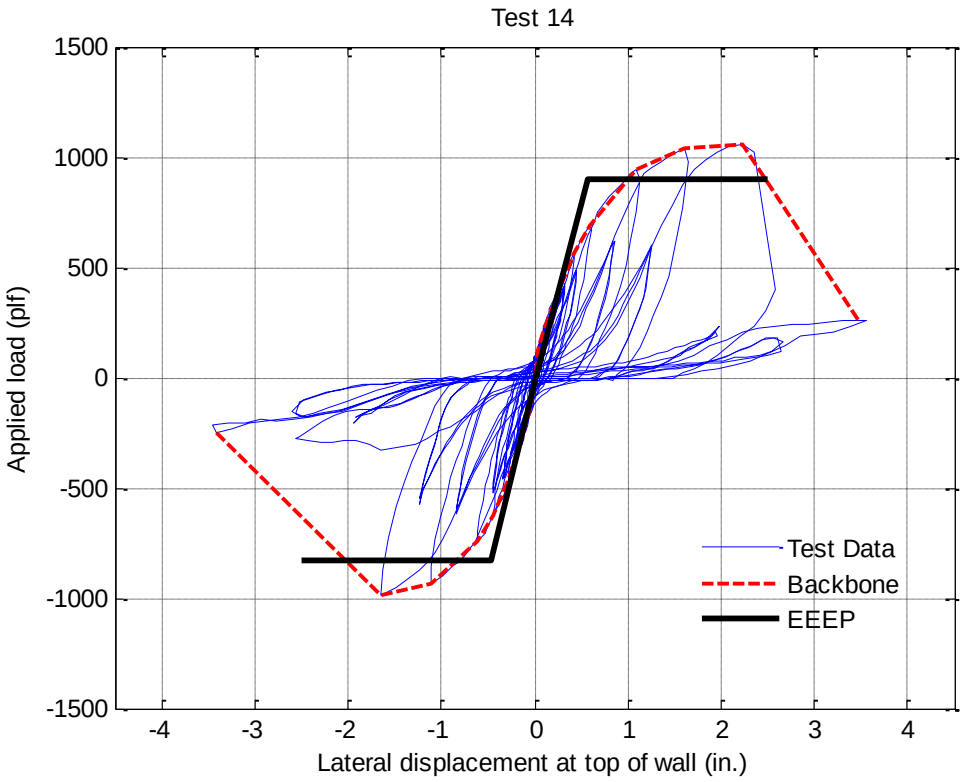

Test 10
1500
1000
500
0
-500
-1000
-1500
Applied load (plf)
-4
-3
-2
-1
0
1
2
3
4
Lateral displacement at top of wall (in.)
Test Data
Backbone
EEEP

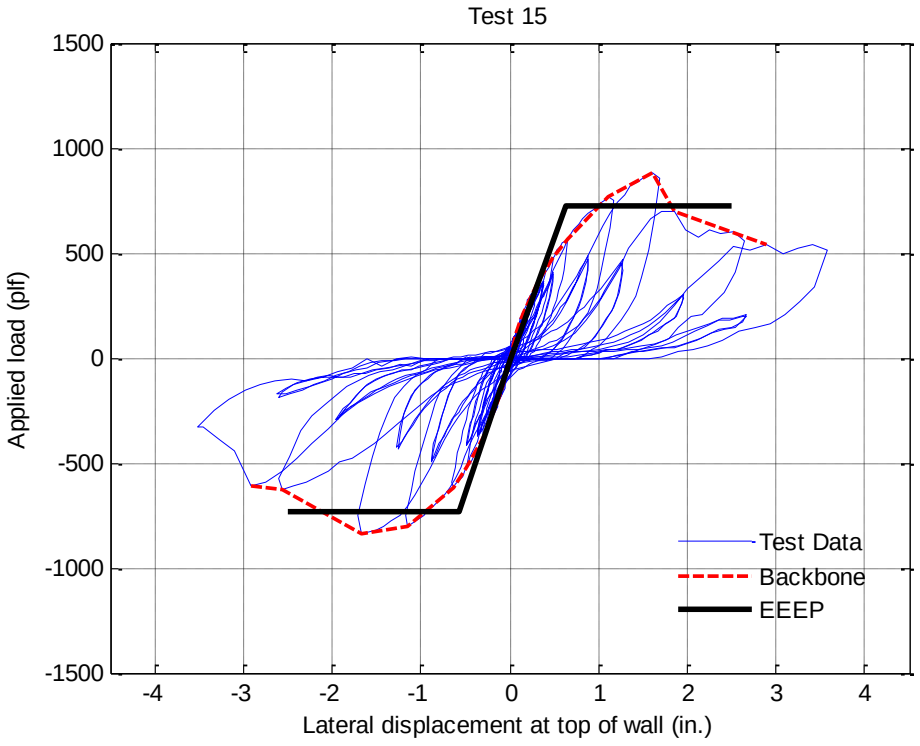

Test 11c
Applied load (plf)
Lateral displacement at top of wall (in.)
Test Data
EEEP
0
200
400
600
800
1000
1200
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5

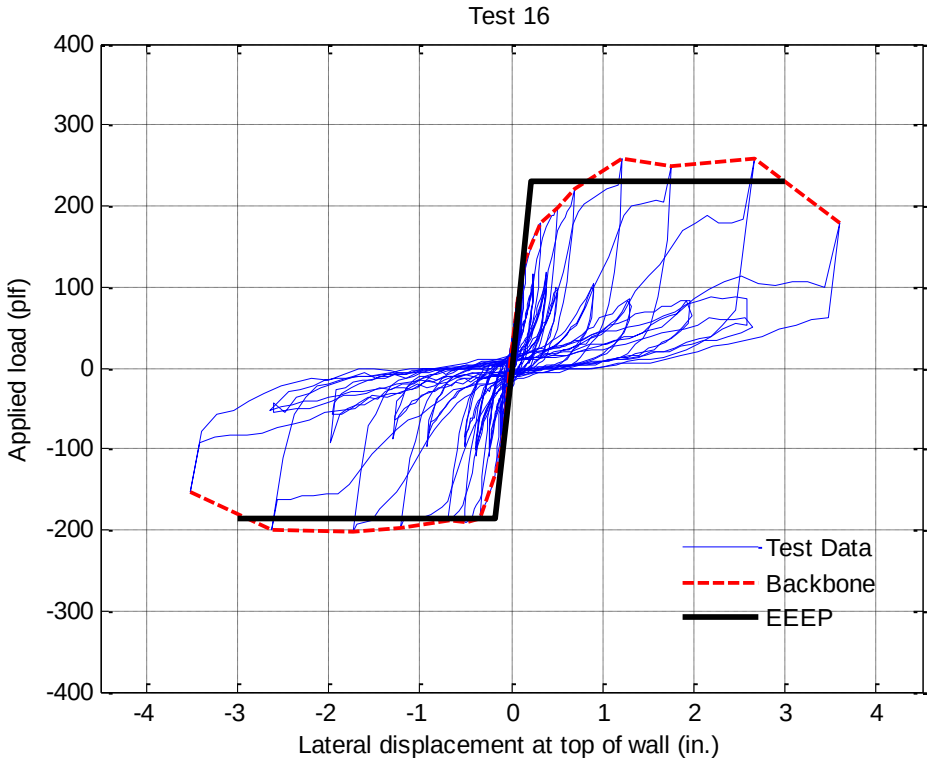

Test 11M
Applied load (plf)
Lateral displacement at top of wall (in.)
Test Data
EEEP
0
100
200
300
400
500
600
0
0.5
1
1.5
2
2.5
3


Test 12
1500
1000
500
0
-500
-1000
-1500
Applied load (plf)
-4
-3
-2
-1
0
1
2
3
4
Lateral displacement at top of wall (in.)
Test Data
Backbone
EEEP


Test 13
1500
1000
500
0
-500
-1000
-1500
Applied load (plf)
-4
-3
-2
-1
0
1
2
3
4
Lateral displacement at top of wall (in.)
Test Data
Backbone
EEEP


Test 14
1500
1000
500
0
-500
-1000
-1500
Applied load (plf)
-4
-3
-2
-1
0
1
2
3
4
Lateral displacement at top of wall (in.)
Test Data
Backbone
EEEP


Test 15
1500
1000
500
0
-500
-1000
-1500
Applied load (plf)
-4
-3
-2
-1
0
1
2
3
4
Lateral displacement at top of wall (in.)
Test Data
Backbone
EEEP


Test 16
400
300
200
100
0
-100
-200
-300
-400
-4
-3
-2
-1
0
1
2
3
4
Applied load (plf)
Lateral displacement at top of wall (in.)
Test Data
Backbone
EEEP