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Durability of Structural Insulated Panels (SIPs) Cyclic Shear Wall Testing
for
The Structural Insulated Panel Association
Gig Harbor, Washington

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by Thomas D. Skaggs, Ph.D., P.E.
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Durability of Structural Insulated Panels (SIPs)Cyclic Shear Wall Testing for The Structural Insulated Panel Association Gig Harbor, Washington

SUMMARY

The purpose of this report is to provide cyclic test data on walls subjected to one of three moisture states: 1) dry condition (as received), 2) wall assemblies subjected to ASTM E72 wetting cycle and permitted to dry for two weeks at laboratory conditions and 3) wall assemblies subjected to ASTM E72 wetting cycles and permitted to dry for four weeks at laboratory conditions. The purpose of this testing is to quantify the durability of SIPs after a standard moisture cycle, and then permitting them to dry for a specific period, to simulate in-field performance.

The cyclic testing was conducted following ASTM E 2126 Method C, CUREE Basic Loading Protocol. The reference deformation, Δ, was set at 2.4 inches. The term α was 0.5. Displacement cycles were added such that the maximum displacement was +/- 4.8 inches.

Based on the testing reported herein, the SIPs performance was insensitive to the ASTM E72 wetting-redry moisture cycles. There was no distinguishable difference between the cyclic performance after a two-week and a four-week redry.

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The precision and bias of the test methods given in this report are being established.

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1. INTRODUCTION

The purpose of this report is to provide cyclic test data on walls subjected to one of three moisture states: 1) dry condition (as received), 2) wall assemblies subjected to ASTM E72 wetting cycle and permitted to dry for two weeks at laboratory conditions and 3) wall assemblies subjected to ASTM E72 wetting cycles and permitted to dry for four weeks at laboratory conditions. The purpose of this testing is to quantify the durability of SIPs after a standard moisture cycle, and then permitting them to dry for a specific period, to simulate in-field performance.

The cyclic testing was conducted following ASTM E 2126 Method C, CUREE Basic Loading Protocol. The reference deformation, Δ, was set at 2.4 inches. The term α was 0.5. Displacement cycles were added such that the maximum displacement was +/- 4.8 inches.

1.1 MATERIAL DESCRIPTION

The cyclic testing summarized in this report examined the performance of one SIPs assembly subjected to an ASTM E72 wetting cycle (Further described in Section 3.5 of this report). The walls were tested in three states, 1) dry (as received), 2) two week redry after the ASTM E72 wetting cycle, and 3) four week redry after the ASTM E72 wetting cycle. The purpose of these tests was to evaluate durability of SIPs when subjected to a wetting cycle, and permitted to dry for a specific period of time. Additional construction details are provided below.

1.2 Framing

The framing lumber for all walls tested was either 2x6 or 2x4 No. 2 & Btr SPF. The framing details can be found in Appendix A. The walls were framed with double 2x4 top plates, with a 2x6 top “cap”. Both of the 2x4s were recessed in the SIP and the 2x6 plate was outside of the sheathing, to yield an overall wall height of 8’ 3”. The two top plates were stitch-nailed together with two rows of 10d common nails (0.148” x 3”) spaced at 8” oc. The end posts were double 2x4s, stitched-nailed identically to the top plates. The single bottom plate, recessed 2x4, was also capped with a 2x6. The two SIPs were attached together with a 7/16” x 3”-wide OSB block spline. The target design value for this assembly was 315 plf, based on the underlying assumption of the SIPs section of the 2009 and 2012 International Residential Code (IRC). The IRC specifies 8d common nails (0.131” x 2-1/2”) with edge nail spacing of 6” oc.

1.3 Fasteners

Three types of nails, representative of typical nails, were used for the tests. The framing nails were full round head strip collated 16d common nails (0.162” x 3-1/2”). The OSB sheathing nails were full round head strip collated 8d common (0.131” x 2-1/2”). The stitch nailing for the double stud vertical members were 10d common nails (0.148” x 3”). In general, the framing nailing followed Table 2304.9.1 of the International Building Code (ICC, 2009 and 2012). Each panel was marked for specific nail location and edge distance.

The stud to top and bottom plate connection was achieved with 2-16d common (0.162” x 3-1/2”) end nails. The sheathing nails, 8d common (0.131” x 2-1/2”), were spaced at 6” on center around the panel perimeter (both sides of the SIPs). The minimum edge distance of the nail placement was 3/8”. The double 2x4 end studs and top and bottom plates were stitch-nailed with two rows of 10d common (0.148” x 3”) spaced at 8” oc.

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1.4 Hold Downs

The hold-down devices were placed on the outside of the SIP walls (See Appendix B, and Figures E2 and E3 in Appendix E), and were positioned to bear on the 2x6 bottom plate cap. The hold downs used for all of the walls were Simpson Strong-Tie HDU4 attached with the accompanied 1/4”-diameter SDS wood screws 3” in length.

1.5 SIPs

The OSB facers were 7/16” OSB manufactured by Tolko Industries, Ltd., Meadow Lake, Saskatchewan, Canada and trademarked with the APA N-610 designation. The SIPs were manufactured by Premier Building Systems, Kent, Washington, on behalf of the Structural Insulated Panel Association, Gig Harbor, Washington. The SIPs were sampled by representatives of Premier Building Systems. The SIPs bore an NTA trademark, and the panels were presumed to be consistent with routine production. Each 4’ x 8’ SIP contained 1-1/2”-diameter vertical (1) and horizontal (2) electrical chases in the EPS core.

2. TEST METHODS

2.1 Instrumentation

For all wall tests, linear potentiometers (LPs) were placed at strategic locations including top plate deformation, bottom plate slipping as well as both end post uplift/compression. See Appendix B for locations of these devices.

The applied load was measured with a load cell located between the MTS hydraulic actuator and the loading head. The loading was applied via displacement mode at a cyclic rate of 0.5 Hz and data was recorded at 500 Hz. The collected data was sampled and averaged so that 100 data points per cycle were reported.

2.2 Cyclic Protocol

The displacement protocol for these tests followed ASTM E2126, Method C, CUREE Basic Loading Protocol. The reference deformation, Δ, was set at 2.4”. The term α was 0.5. Displacement cycles were added such that the maximum displacement was +/- 4.8”.

2.3 Boundary Conditions

The OSB sheathing on all walls was restrained with 2x6 SPF top and bottom plates. These plates capped the walls and simulated end-use boundary conditions. To be consistent with ASTM E2126, the anchor bolts (5/8” diameter) were torqued with the nuts no tighter than finger tight plus 1/4 turn. The hold-down bolts were consistently tight for all walls. The thread pitch on all bolts was standard UNC (coarse). The loading beam (Appendix B, and Figures E2, E4, and E5 in Appendix E) was a custom built-up channel from two L3 x 2-1/2 x 3/8 angles, welded toe-to-toe for a net width of 5 inches in width. The resulting bending stiffness EI of the loading beam is 121 x 10^6 lbf-in.^{2}. The built-up shape was attached with enough 1/4” x 3” lag screws to develop the capacity of the walls.

2.4 SIP Cyclic Test Specimen Description

All SIP wall assemblies were tested in July 2011. Details of the wall construction can be found in Section 2 of this report. There were three replications for the dry SIPs tests, and three replications for the wet-redry specimens.

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Of the wet-redry specimens, two were permitted to dry to lab conditions for a period of two weeks, and the remaining wet-redry specimen was permitted to dry to lab conditions for a period of four weeks.

2.5 ASTM E72 Wetting Cycle

The wetting cycle followed Section 15.3 of ASTM E72. In summary, the specimens were suspended in a vertical position that prevented continuous immersion of the bottom edge of the SIP assemblies. Both sides of the specimens were exposed to a water spray near the top and along the length of the specimen. The water was permitted to flow down both surfaces of the specimens. Note that portions of the SIPs facers were removed for double electrical boxes at the mid-height and at the lower height foam electrical chases (See Figure E2) before the wetting cycle. The facers were removed on only one side of the SIP. The specimens were wetted for a period of 6 hours, and then permitted to air dry for a period of 18 hours with laboratory air, with no increase in air movement. This wetting cycle was repeated for two additional cycles. After the wetting cycles, the walls were permitted to air dry at lab conditions, with no additional air movement for two and four weeks.

3. RESULTS AND DISCUSSION

The average panel facer moisture content was 5.1%, 7.4%, 6.6% for the dry, two-week redry and four-week redry, respectively. Clearly the moisture cycle resulted in elevated moisture content of SIP facers as well as the additional two weeks of drying was effective in reducing moisture content. The lumber moisture content (ASTM D4442) and the specific gravity (ASTM D2395) for these wall tests are listed in Appendix B. The average 2x4 moisture content was 11.1% for the specimens tested in the dry condition. The 2x4s from the redried specimens were 11.8% and 12.2% for the two-week and four-week redry, respectively. The average 2x6 moisture content was 11.5%, 12.9%, and 12.7% for the dry, two-week redry and four-week redry, respectively. The average specific gravity of the 2x4s was 0.45, 0.47 and 0.43 for the dry, two-week redry and four-week redry respectively. The 2x6 specific gravity is listed in Appendix B.

The applied load versus the horizontal wall displacement can be found in Appendix C. Each of the hysteretic plots shows a backbone curve, as well as an equivalent energy elastic-plastic (EEEP) curve, as defined by ASTM E2126. In addition to the individual plots, a detailed data analysis per ASTM E2126 is provided in Appendix C.

Table 1 lists a summary of the average cyclic properties for the different SIPs and conventional walls, as well as comparison to established criteria for lateral force resisting systems as presented in ICC ES AC04. A more detailed summary of these data can be found in Appendix D.

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Table 1. Average summary statistics for walls tested and analyzed in accordance with ICC ES AC04.

Wall Detail	ASD Design Value (1) (plf)	ASD Design Defl. (2) (in.)	Ultimate Defl. (2) (in.)	Peak Load (2) (plf)	ICC ES AC 04 Analysis Section Number		
					A3.3.2 (3)	A3.3.3 (4)	A3.3.4 (5)
Dry	315	0.081	2.464	1,220	30.7	0.026	3.87
Wet-Redry (2 weeks)	315	0.111	2.776	1,247	25.1	0.029	3.96
Wet-Redry (4 weeks)	315	0.094	2.605	1,247	27.8	0.027	3.96

(1) See Section 4 of this report for more details on wall construction and rationale for design value.
(2) Based on the average of the absolute value of positive and negative cyclic excursion.
(3) Ultimate deflection divided by deflection at design value. AC04 Appendix A criteria requires this property to be greater than or equal to 11.
(4) Minimum post peak displacement. AC04 Appendix A criteria requires this property to be greater than or equal to 0.028H, based on tests following CUREE loading protocol.
(5) Peak strength divided by design value. AC04 Appendix A criterion for this property requires this property to be between 2.5 and 5.0.

4. ANALYSIS TO DEMONSTRATE EQUIVALENT CYCLIC PROPERTIES

The primary failure mode of the SIPs was the top plate tearing out of the wall toward the end of the displacement cycles (Figure E4 and E5). There was no significant difference in the failure modes associated with the different moisture cycles of the walls.

Based on the cyclic test results summarized in this report, a detailed analysis in accordance with AC04 was conducted. ICC ES AC04 Appendix A was created to provide a methodology for benchmarking SIPs cyclic test data to light frame walls sheathed with wood structural panels, based on established criteria. The criteria was intended to confirm compatibility with a code defined seismic-force resisting system – light-frame walls sheathed with wood structural panels rated for shear resistance (Seismic Force-Resisting System A-13 in accordance with Table 12-2.1 of ASCE 7-05). The walls summarized herein were considered as “Assembly C” in accordance with AC04.

The first criterion was intended to provide similar ductility as light-frame walls sheathed with wood structural panels (Section A3.3.2, requiring ultimate deflection divided by deflection at ASD design value to be greater than or equal to 11). The second criteria is intended to show that the ultimate failure deflection of the walls is similar to light-frame walls sheathed with wood structural panels (Section A3.3.3, requiring minimum post peak displacement of 0.028H, where H is the height of the wall). The final criterion is intended to provide load factors that are similar to light-frame walls sheathed with wood structural panels, yet limit the overstrength of the panels (Section A3.3.4, requiring peak strength divided by design values to be between 2.5 and 5.0).

One of the underlying assumptions of the ICC ES AC04 Appendix A analysis is the ASD design value. The ASD design values for these walls were based on 315 plf, which is consistent with the underlying assumptions of the prescriptive SIPs portion of the 2009 and 2012 IRC. The summary information in Table 1 above is based on this design information.

The three rightmost columns of Table 1 provide an average summary of the aforementioned evaluation attributes, respectively. A more detailed analysis for each individual wall test is provided in Appendix D.

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In general, there was no distinguishable difference in the walls tested dry and the walls tested in the redry state after the wetting cycle. The post peak deformation was very close to the 0.028H criteria for all walls tested.

5. CONCLUSION

Based on the testing reported herein, the SIPs performance was insensitive to the wetting-redry moisture cycles. There was no distinguishable difference between the cyclic performance after a two-week and a four-week redry.

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7. APPENDICES

List of Appendices

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Appendix A: Wall Construction Details (2 pages)

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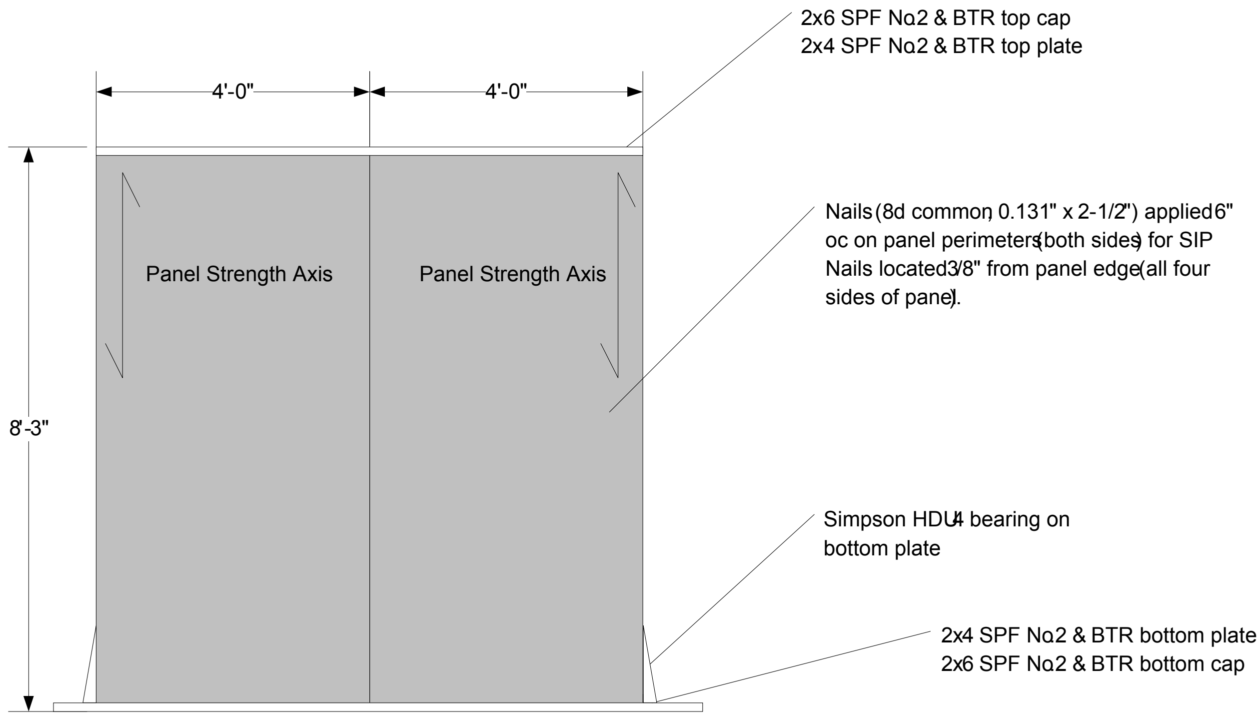
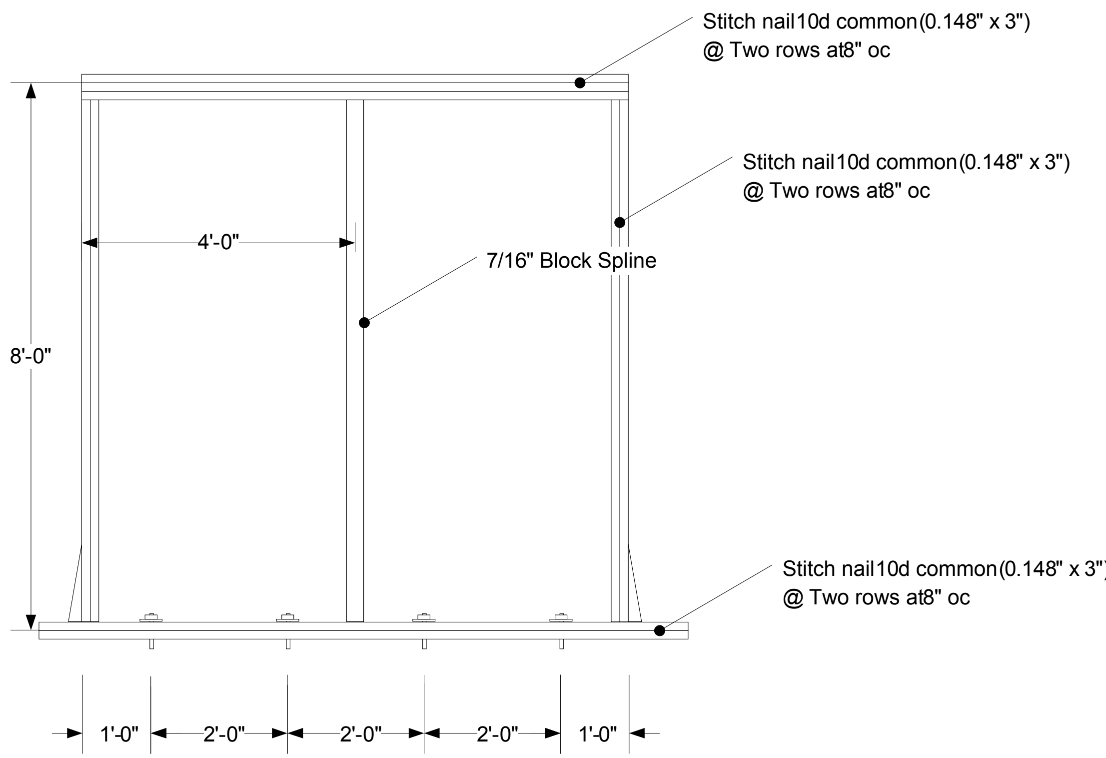


Panel layout for SIP wall tests



Framing layout for SIP wall tests

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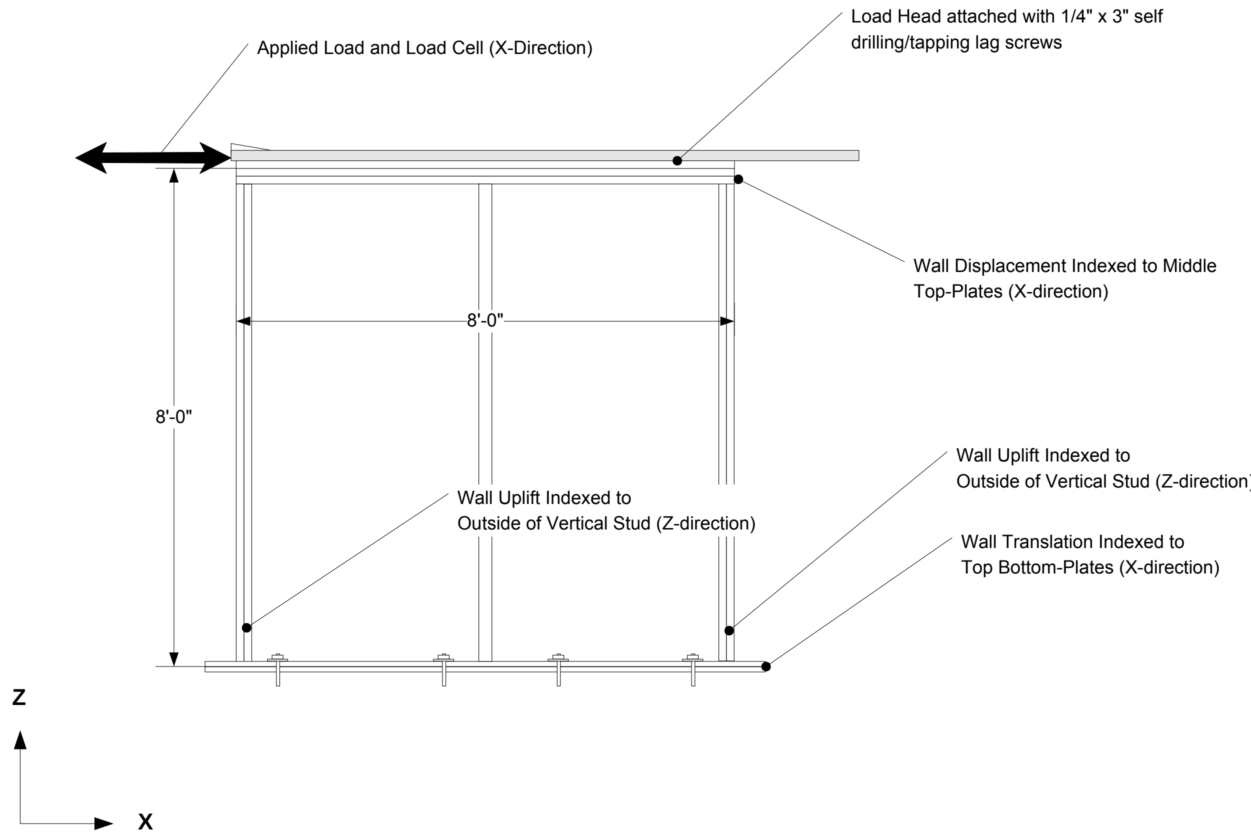

Instrumentation layout for SIP wall tests

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Appendix B: Facer and Lumber Moisture Content and Specific Gravity (2 pages)

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Panel Moisture Content

Technician:	Kevin Kallansrud
Date:	7/12/2011
Company:	SIPA
Location:	Gig Harbor, Washington
Product:	Facer Material for Racking Tests
Project:	7646
Balance:	JB6001-G

Specimen Number	As-received Weight (g)	Oven Dry Weight (g)	Moisture Content (%)
dry 1	n.a.	n.a.	n.a.
dry 1	n.a.	n.a.	n.a.
dry 2	433.5	413.6	4.8
dry 2	270.1	257.3	5.0
dry 3	483.3	458.8	5.3
dry 3	354.4	336.9	5.2
Summary Statistics, Dry	Count		4
	Min		4.8
	Max		5.3
	Mean		5.1
	Std Dev		0.2
	COV (%)		4.6
redry 1	240.4	222.5	8.0
redry 1	290.6	271.7	7.0
redry 2	478.7	446.5	7.2
redry 2	347.9	323.7	7.5
Summary Statistics, 2 week Redry	Count		4
	Min		7.0
	Max		8.0
	Mean		7.4
	Std Dev		0.5
	COV (%)		6.3
redry 3	429.1	401.5	6.9
redry 3	460.7	432.9	6.4
Summary Statistics, 4 week Redry	Count		2
	Min		6.4
	Max		6.9
	Mean		6.6
	Std Dev		0.3
	COV (%)		4.8

Thomas D. Skaggs

Data analyzed by: Thomas D. Skaggs, Ph.D., P.E.

Lumber Moisture Content and Specific Gravity

Technician:	Kevin Kallansrud
Date:	7/29/2011
Company:	SIPA
Location:	Gig Harbor, Washington
Product:	SPF stud material for shear walls
Project:	7371
Caliper:	QLT 51
Balance:	JB6001-G

Specimen Number	As-received				Oven Dry	As-received	Oven Dry	Specific	Moisture
	Weight (g)	Length (in.)	Width (in.)	Thick (in.)	Weight (g)	Density (pcf)	Density (pcf)	Gravity	Content (%)
1 dry bot	179.8	4.300	3.449	1.462	159.9	31.6	28.1	0.45	12.4
1 dry i top	197.4	5.030	3.489	1.495	178.9	28.7	26.0	0.42	10.3
1 dry top	199.3	5.101	3.483	1.495	179.9	28.6	25.8	0.41	10.8
2 dry bot	143.2	3.390	3.469	1.482	127.6	31.3	27.9	0.45	12.2
2 dry i top	183.4	4.232	3.449	1.475	165.4	32.5	29.3	0.47	10.9
2 dry top	207.9	4.649	3.485	1.505	188.4	32.5	29.4	0.47	10.4
3 dry bot	288.9	8.348	3.496	1.502	258.5	25.1	22.5	0.36	11.8
3 dry i top	180.7	3.647	3.460	1.494	163.5	36.5	33.0	0.53	10.5
3 dry top	162.0	3.688	3.219	1.494	146.8	34.8	31.5	0.51	10.4
	Count							9	9
	Min							0.36	10.3
Summary Statistics, Dry 2x4s	Max							0.53	12.4
	Mean							0.45	11.1
	Std Dev							0.05	0.8
	COV (%)							11.3	7.6
1 dry 2x6 bot	287.9	4.537	5.475	1.473	257.3	30.0	26.8	0.43	11.9
1 dry 2x6 top	335.1	5.331	5.492	1.493	302.7	29.2	26.4	0.42	10.7
2 dry 2x6 bot	237.1	4.877	4.159	1.496	212.2	29.8	26.6	0.43	11.7
2 dry 2x6 top	323.2	5.930	5.481	1.479	290.4	25.6	23.0	0.37	11.3
3 dry 2x6 bot	301.6	5.234	5.477	1.485	268.6	27.0	24.0	0.39	12.3
3 dry 2x6 top	215.0	4.010	5.462	1.484	193.2	25.2	22.6	0.36	11.3
	Count							6	6
	Min							0.36	10.7
Summary Statistics for Dry, 2x6s	Max							0.43	12.3
	Mean							0.40	11.5
	Std Dev							0.03	0.6
	COV (%)							7.7	4.8
1 redry bot	215.6	4.028	3.479	1.479	188.6	39.6	34.7	0.56	14.3
1 redry i top	239.6	5.478	3.482	1.495	216.1	32.0	28.9	0.46	10.9
1 redry top	237.1	5.541	3.489	1.500	213.9	31.2	28.1	0.45	10.8
2 redry bot	189.1	4.661	3.487	1.493	164.9	29.7	25.9	0.41	14.7
2 redry i top	425.9	10.027	3.483	1.495	389.6	31.1	28.4	0.46	9.3
2 redry top	198.5	4.688	3.470	1.487	178.8	31.3	28.2	0.45	11.0
	Count							6	6
	Min							0.41	9.3
Summary Statistics, 2 week Redry 2x4s	Max							0.56	14.7
	Mean							0.47	11.8
	Std Dev							0.05	2.2
	COV (%)							10.2	18.2
1 redry 2x6 bot	292.6	4.414	5.459	1.488	256.7	31.1	27.3	0.44	14.0
1 redry 2x6 top	365.0	5.925	5.406	1.471	326.1	29.5	26.4	0.42	11.9
2 redry 2x6 bot	237.8	3.704	5.484	1.500	208.7	29.7	26.1	0.42	13.9
2 redry 2x6 top	281.4	5.632	5.415	1.503	251.5	23.4	20.9	0.34	11.9
	Count							4	4
	Min							0.34	11.9
Summary Statistics, 2 week Redry 2x6s	Max							0.44	14.0
	Mean							0.40	12.9
	Std Dev							0.05	1.2
	COV (%)							11.5	9.2
3 redry bot	224.3	5.729	3.484	1.494	194.6	28.7	24.9	0.40	15.3
3 redry i top	259.4	5.717	3.461	1.476	234.2	33.8	30.6	0.49	10.8
3 redry top	250.7	6.380	3.494	1.491	226.8	28.7	26.0	0.42	10.5
	Count							3	3
	Min							0.40	10.5
Summary Statistics, 4 week Redry 2x4s	Max							0.49	15.3
	Mean							0.43	12.2
	Std Dev							0.05	2.7
	COV (%)							11.1	21.9
3 redry 2x6 bot	414.5	5.662	5.489	1.499	363.3	33.9	29.7	0.48	14.1
3 redry 2x6 top	301.6	5.808	5.468	1.470	270.9	24.6	22.1	0.35	11.3
	Count							2	2
	Min							0.35	11.3
Summary Statistics, 4 week Redry 2x6s	Max							0.48	14.1
	Mean							0.42	12.7
	Std Dev							0.09	2.0
	COV (%)							20.7	15.4

Thomas D. Skaggs

Data analyzed by: Thomas D. Skaggs, Ph.D., P.E.

Appendix C: Structural Insulated Panels Cyclic Data (10 pages)

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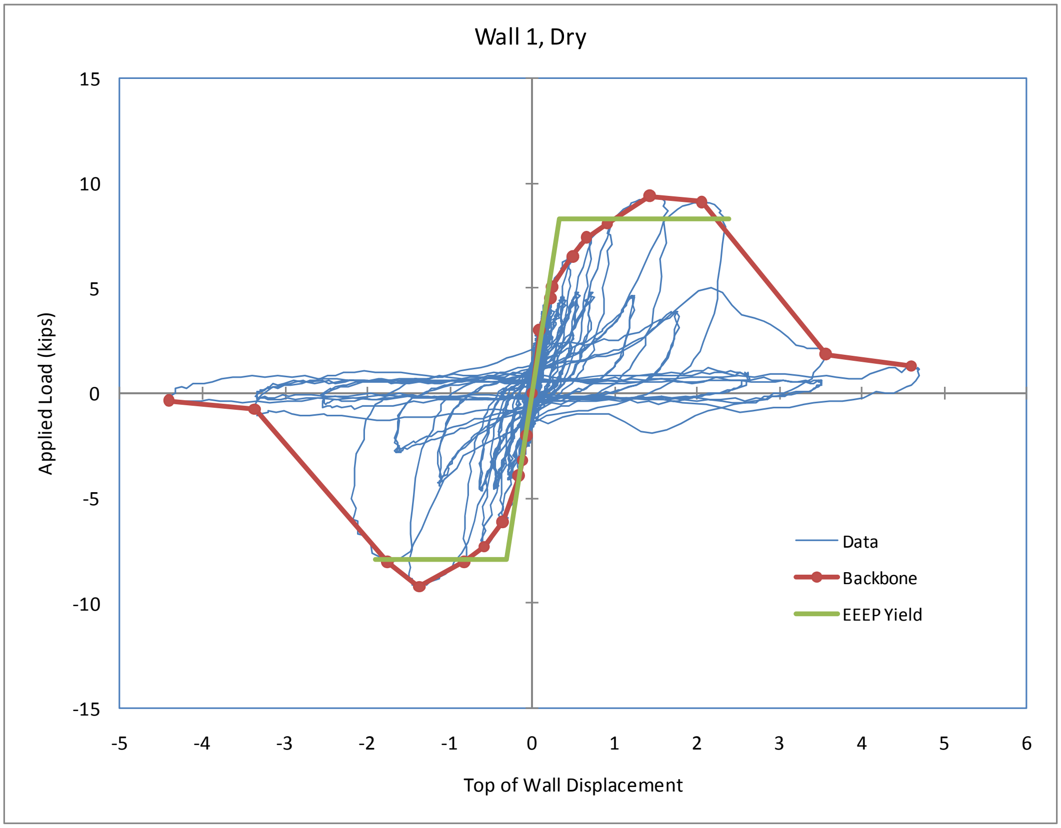

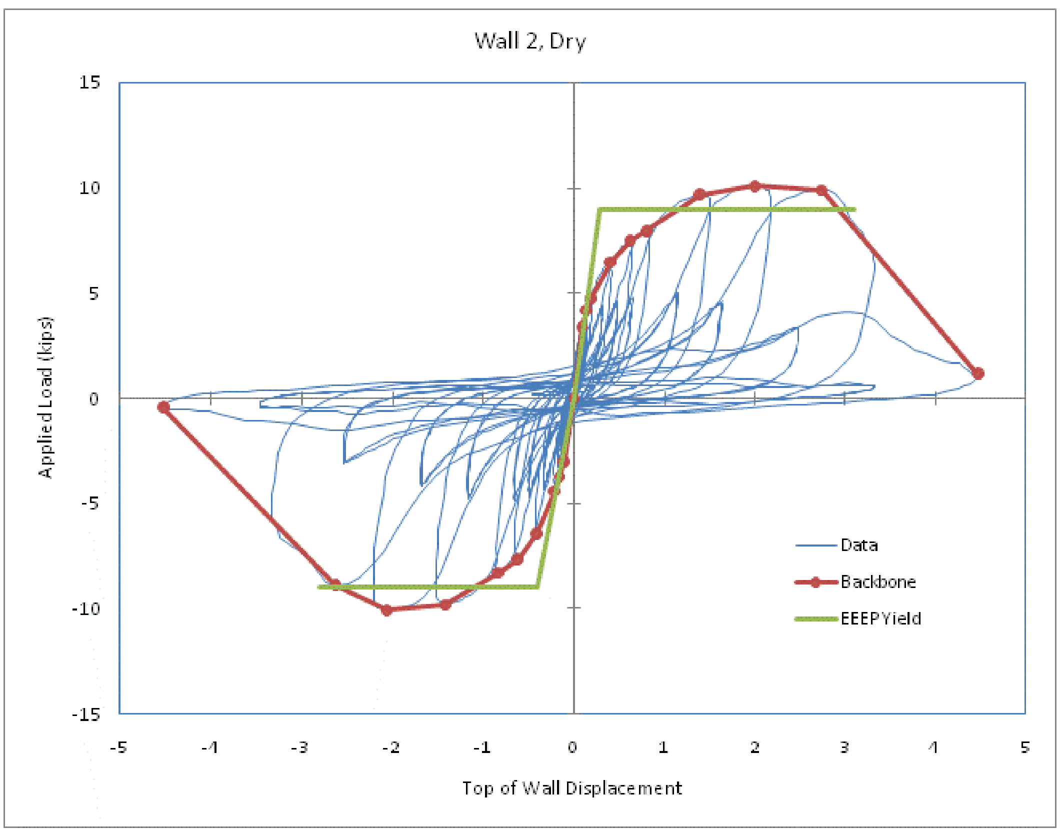

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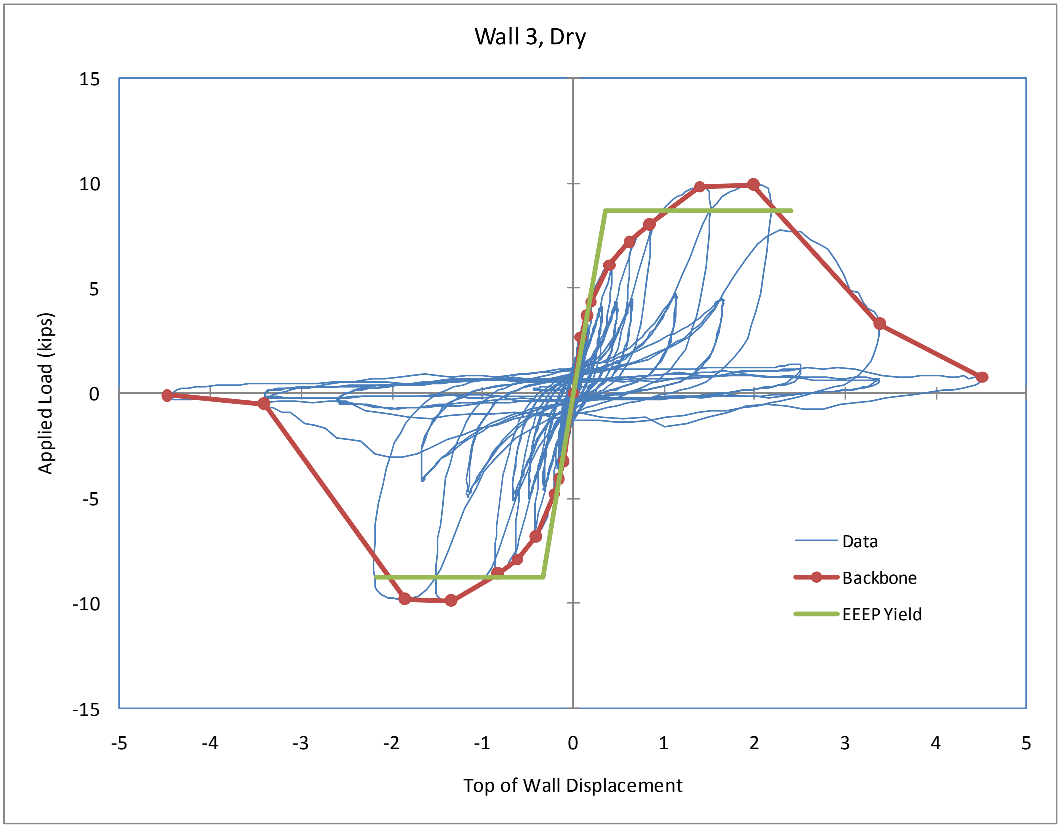

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Specimen **Dry1**	**For total length**		**Specimen** **Dry1**	**Per unit length**	
Dry 1	**CUREE cyclic test**		Dry 1	**CUREE cyclic test**	
Effective wall length	**96in.**	**2.44m**	**Effective wall length**	**96in.**	**2.44m**
Date: 7/8/2011	**Time:**	15:26	**Date:** 7/8/2011	**Time:**	15:26
EEEP Parameters	**units**	**initial**	**EEEP Parameters**	**units**	**initial**
Peak load, F_{peak}	Kips	9.289	Peak unit load, v_{peak}	Kip/ft.	1.161
	KN	41.317		KN/m	16.944
Drift at peak load, Δ_{peak}	in.	1.397	Drift at capacity, Δ_{peak}	in.	1.397
	mm	35.47		mm	35.47
Yield load, F_{yield}	Kips	8.107	Yield unit load, v_{yield}	Kip/ft.	1.013
	KN	36.059		KN/m	14.788
Drift at yield load, Δ_{yield}	in.	0.325	Drift at yield load, Δ_{yield}	in.	0.325
	mm	8.26		mm	8.26
Proportional limit,	Kips	3.716	Proportional limit,	Kip/ft.	0.464
$0.4F_{peak}$	KN	16.527	$0.4v_{peak}$	KN/m	6.778
Drift at prop. limit,	in.	0.149	Drift at prop. limit,	in.	0.149
$\Delta@0.4F_{peak}$	mm	3.79	$\Delta@0.4v_{peak}$	mm	3.79
Failure load or $0.8F_{peak}$	Kips	7.431	Unit load at failure or	Kip/ft.	0.929
	KN	33.053	$0.8v_{peak}$	KN/m	13.555
Drift at failure, $\Delta_{failure}$	in.	2.147	Drift at failure, $\Delta_{failure}$	in.	2.147
	mm	54.54		mm	54.54
Elastic stiffness, K_e	Kip/in.	24.925	Shear modulus, G	Kip/in.	24.925
$@0.4F_{peak}$	KN/mm	4.365	$@0.4F_{peak}$	KN/mm	4.365
Work until failure	Kip·ft.	9.860	Work until failure per	Kip·ft./ft.	1.232
	KN·m	13.367	unit length	KN·m/m	5.482
Load @ .32 in.	Kips	5.616	Unit load @ .32 in.	Kips/ft.	0.702
(8.13 mm)	KN	24.982	(8.13 mm)	KN/m	10.245
Load @ .48 in.	Kips	6.616	Unit load @ .48 in.	Kips/ft.	0.827
(12.19 mm)	KN	29.429	(12.19 mm)	KN/m	12.069
Load @ .96 in.	Kips	8.252	Unit load @ .96 in.	Kips/ft.	1.031
(24.38 mm)	KN	36.704	(24.38 mm)	KN/m	15.052
Load @ 1.6 in.	Kips	8.908	Unit load @ 1.6 in.	Kips/ft.	1.113
(40.64 mm)	KN	39.622	(40.64 mm)	KN/m	16.249
Ductility factor, μ		6.59	$\zeta_{eq}@v_{peak}$		0.201

Specimen **Dry1**	**For total length**													
Dry 1	**CUREE cyclic test**													
Effective wall length	**96in.**	**2.44m**												
cycle	**avg. displacement**		**avg. load**		**work per cycle**		**cumulative work**		**cyclic stiffness**		**damping**	**line**
initial	in.	mm	Kips	KN	Kip·ft.	KN·m	Kip·ft.	KN·m	Kip/in.	KN/mm	**ratio**	**number**
	0	0	0	0	0	0	0	0				13
1	0.082	2.070	2.503	11.135	0.016	0.022	0.016	0.022	30.449	5.332	0.150	102
7	0.166	4.224	3.863	17.182	0.052	0.070	0.208	0.282	24.035	4.209	0.146	753
14	0.200	5.085	4.489	19.966	0.076	0.102	0.478	0.648	22.670	3.970	0.157	1517
21	0.424	10.757	6.325	28.134	0.241	0.327	1.012	1.372	15.230	2.667	0.171	2286
25	0.621	15.776	7.360	32.736	0.386	0.523	1.721	2.333	11.883	2.081	0.161	2729
29	0.867	22.024	8.042	35.770	0.514	0.696	2.683	3.637	9.298	1.628	0.141	3174
32	1.397	35.475	9.289	41.317	1.364	1.850	4.446	6.028	6.652	1.165	0.201	3508
35	1.904	48.365	8.577	38.152	1.892	2.565	7.100	9.626	4.510	0.790	0.220	3842
38	1.804	45.828	3.473	15.448	1.579	2.140	9.860	13.367	0.502	0.088	0.745	4175
41	3.558	90.373	1.096	4.877	0.776	1.053	11.477	15.560	-0.041	-0.007	0.827	4509

cycle	**Negative stroke**		**Positive stroke**		**Negative stroke**		**Positive stroke**		**Area**, Kip-in.		**Unit load**, KN/m	
initial	in.	Kips	in.	Kips	mm	KN	mm	KN	negative	positive	negative	positive
	0	0	0	0	0	0	0	0	0	0	0	0
1	-0.076	-2.020	0.087	2.987	-1.923	-8.986	2.217	13.285	0.076	0.130	-3.685	5.448
7	-0.119	-3.197	0.214	4.528	-3.023	-14.222	5.425	20.142	0.113	0.475	-5.833	8.260
14	-0.164	-3.934	0.237	5.043	-4.158	-17.499	6.012	22.433	0.159	0.111	-7.177	9.200
21	-0.358	-6.130	0.489	6.520	-9.088	-27.267	12.426	29.001	0.977	1.460	-11.182	11.893
25	-0.586	-7.320	0.656	7.399	-14.895	-32.560	16.657	32.912	1.537	1.159	-13.353	13.497
29	-0.822	-8.027	0.912	8.057	-20.886	-35.703	23.162	35.837	1.810	1.979	-14.642	14.697
32	-1.373	-9.209	1.421	9.369	-34.869	-40.961	36.081	41.672	4.744	4.431	-16.798	17.090
35	-1.757	-8.043	2.051	9.112	-44.635	-35.774	52.095	40.531	3.317	5.826	-14.671	16.622
38	-3.368	-0.773	3.562	1.851	-85.552	-3.439	90.482	8.232	7.101	8.284	-1.410	3.376
41	-4.404	-0.363	4.592	1.282	-111.864	-1.614	116.632	5.702	0.588	1.612	-0.662	2.338

Data analyzed by: Thomas D. Skaggs, Ph.D., P.E.

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Specimen Dry2	For total length		Specimen Dry2	Per unit length	
Dry 2	CUREE cyclic test		Dry 2	CUREE cyclic test	
Effective wall length	96in.	2.44m	Effective wall length	96in.	2.44m
Date: 7/12/2011	Time:	11:03	Date: 7/12/2011	Time:	11:03
EEEP Parameters	**units**	**initial**	**EEEP Parameters**	**units**	**initial**
Peak load, F_{peak}	Kips	10.091	Peak unit load, v_{peak}	Kip/ft.	1.261
	KN	44.886		KN/m	18.408
Drift at peak load, Δ_{peak}	in.	2.028	Drift at capacity, Δ_{peak}	in.	2.028
	mm	51.51		mm	51.51
Yield load, F_{yield}	Kips	8.982	Yield unit load, v_{yield}	Kip/ft.	1.123
	KN	39.952		KN/m	16.385
Drift at yield load, Δ_{yield}	in.	0.349	Drift at yield load, Δ_{yield}	in.	0.349
	mm	8.86		mm	8.86
Proportional limit, $0.4F_{peak}$	Kips	4.037	Proportional limit, $0.4v_{peak}$	Kip/ft.	0.505
	KN	17.954		KN/m	7.363
Drift at prop. limit, $\Delta@0.4F_{peak}$	in.	0.157	Drift at prop. limit, $\Delta@0.4v_{peak}$	in.	0.157
	mm	3.98		mm	3.98
Failure load or $0.8F_{peak}$	Kips	8.073	Unit load at failure or $0.8v_{peak}$	Kip/ft.	1.009
	KN	35.909		KN/m	14.726
Drift at failure, $\Delta_{failure}$	in.	2.956	Drift at failure, $\Delta_{failure}$	in.	2.956
	mm	75.08		mm	75.08
Elastic stiffness, K_e @$0.4F_{peak}$	Kip/in.	26.565	Shear modulus, G @$0.4F_{peak}$	Kip/in.	26.565
	KN/mm	4.652		KN/mm	4.652
Work until failure	Kip·ft.	13.176	Work until failure per unit length	Kip·ft./ft.	1.647
	KN·m	17.864		KN·m/m	7.326
Load @ .32 in. (8.13 mm)	Kips	5.653	Unit load @ .32 in. (8.13 mm)	Kips/ft.	0.707
	KN	25.146		KN/m	10.312
Load @ .48 in. (12.19 mm)	Kips	6.832	Unit load @ .48 in. (12.19 mm)	Kips/ft.	0.854
	KN	30.387		KN/m	12.462
Load @ .96 in. (24.38 mm)	Kips	8.525	Unit load @ .96 in. (24.38 mm)	Kips/ft.	1.066
	KN	37.921		KN/m	15.551
Load @ 1.6 in. (40.64 mm)	Kips	9.862	Unit load @ 1.6 in. (40.64 mm)	Kips/ft.	1.233
	KN	43.865		KN/m	17.989
Ductility factor, μ		8.82	ζ_{eq} @v_{peak}		0.166

Specimen Dry2	For total length	
Dry 2	CUREE cyclic test	
Effective wall length	96in.	2.44m

cycle	avg. displacement		avg. load		work per cycle		cumulative work		cyclic stiffness		damping	line
initial	in.	mm	Kips	KN	Kip·ft.	KN·m	Kip·ft.	KN·m	Kip/in.	KN/mm	ratio	number
	0	0	0	0	0	0	0	0				13
1	0.098	2.502	3.190	14.190	0.027	0.036	0.027	0.036	32.881	5.758	0.163	109
7	0.149	3.774	3.951	17.573	0.045	0.061	0.194	0.263	26.854	4.703	0.146	778
14	0.201	5.112	4.585	20.392	0.070	0.094	0.424	0.575	22.940	4.017	0.144	1557
21	0.406	10.325	6.448	28.680	0.224	0.304	0.876	1.188	15.864	2.778	0.163	2333
25	0.620	15.758	7.571	33.677	0.367	0.497	1.499	2.033	12.204	2.137	0.149	2777
29	0.816	20.715	8.123	36.133	0.470	0.638	2.347	3.182	9.961	1.744	0.136	3222
32	1.406	35.704	9.753	43.381	1.304	1.768	3.978	5.393	6.939	1.215	0.182	3555
35	2.028	51.507	10.091	44.886	1.774	2.405	6.379	8.648	4.978	0.872	0.166	3888
38	2.687	68.246	9.380	41.722	2.937	3.981	10.265	13.917	3.489	0.611	0.222	4222
41	2.846	72.296	2.839	12.629	1.523	2.065	13.176	17.864	0.972	0.170	0.350	4555

cycle	Negative stroke		Positive stroke		Negative stroke		Positive stroke		Area, Kip-in.		Unit load, KN/m	
initial	in.	Kips	in.	Kips	mm	KN	mm	KN	negative	positive	negative	positive
	0	0	0	0	0	0	0	0	0	0	0	0
1	-0.108	-2.999	0.089	3.381	-2.743	-13.341	2.261	15.040	0.162	0.150	-5.471	6.168
7	-0.160	-3.733	0.137	4.169	-4.061	-16.604	3.487	18.542	0.175	0.182	-6.809	7.604
14	-0.215	-4.414	0.188	4.755	-5.453	-19.635	4.770	21.150	0.223	0.225	-8.052	8.674
21	-0.411	-6.428	0.402	6.468	-10.437	-28.592	10.213	28.768	1.064	1.203	-11.726	11.798
25	-0.622	-7.678	0.619	7.464	-15.789	-34.153	15.728	33.201	1.486	1.512	-14.006	13.616
29	-0.833	-8.301	0.798	7.946	-21.158	-36.922	20.272	35.344	1.689	1.378	-15.142	14.495
32	-1.420	-9.817	1.391	9.689	-36.073	-43.667	35.334	43.096	5.319	5.229	-17.908	17.674
35	-2.064	-10.080	1.992	10.102	-52.418	-44.837	50.597	44.935	6.402	5.946	-18.388	18.428
38	-2.628	-8.882	2.746	9.877	-66.746	-39.509	69.746	43.935	5.348	7.531	-16.203	18.018
41	-4.524	-0.433	4.467	1.165	-114.899	-1.924	113.467	5.180	8.830	9.503	-0.789	2.124

Data analyzed by: Thomas D. Skaggs, Ph.D., P.E.

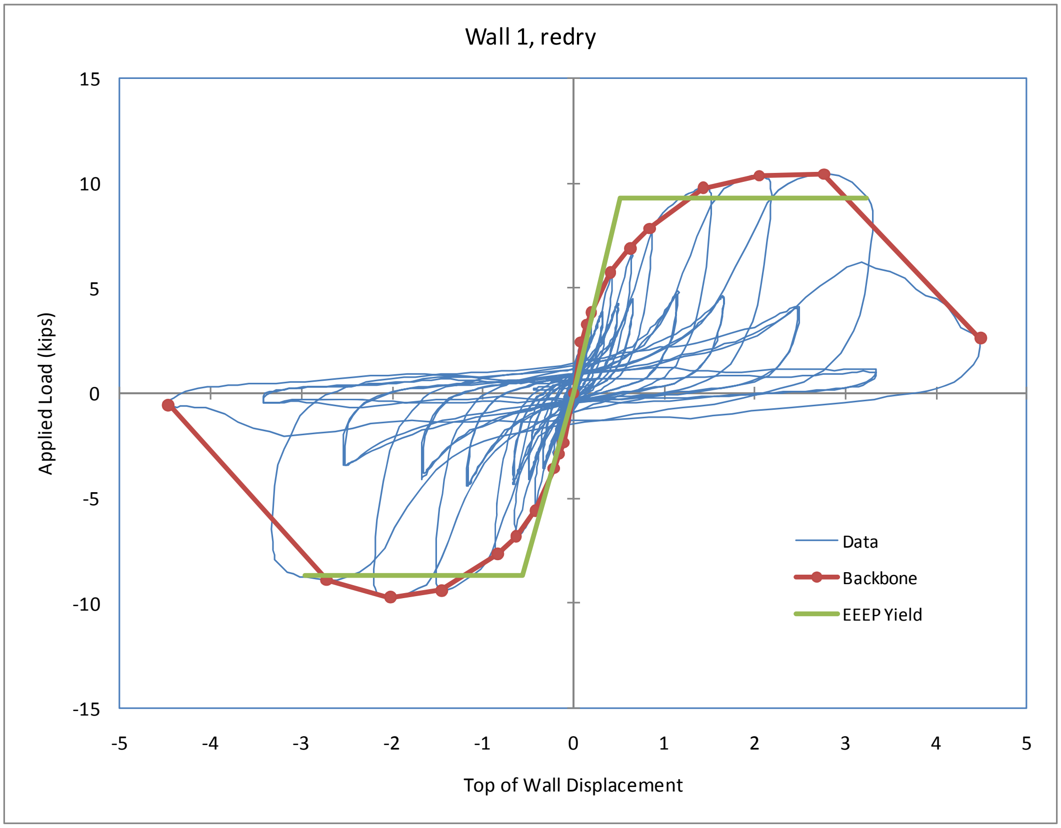
Specimen dry3	For total length		Specimen dry3	Per unit length	
dry 3	CUREE cyclic test		dry 3	CUREE cyclic test	
Effective wall length	**96in.**	**2.44m**	**Effective wall length**	**96in.**	**2.44m**
Date: 7/12/2011	**Time:**	15:23	**Date:** 7/12/2011	**Time:**	15:23
EEEP Parameters	**units**	**initial**	**EEEP Parameters**	**units**	**initial**
Peak load, F_{peak}	Kips	9.897	Peak unit load, v_{peak}	Kip/ft.	1.237
	KN	44.023		KN/m	18.054
Drift at peak load, Δ_{peak}	in.	1.664	Drift at capacity, Δ_{peak}	in.	1.664
	mm	42.26		mm	42.26
Yield load, F_{yield}	Kips	8.715	Yield unit load, v_{yield}	Kip/ft.	1.089
	KN	38.766		KN/m	15.898
Drift at yield load, Δ_{yield}	in.	0.346	Drift at yield load, Δ_{yield}	in.	0.346
	mm	8.79		mm	8.79
Proportional limit, $0.4F_{peak}$	Kips	3.959	Proportional limit, $0.4v_{peak}$	Kip/ft.	0.495
	KN	17.609		KN/m	7.222
Drift at prop. limit, $\Delta@0.4F_{peak}$	in.	0.157	Drift at prop. limit, $\Delta@0.4v_{peak}$	in.	0.157
	mm	3.99		mm	3.99
Failure load or $0.8F_{peak}$	Kips	7.918	Unit load at failure or $0.8v_{peak}$	Kip/ft.	0.990
	KN	35.218		KN/m	14.443
Drift at failure, $\Delta_{failure}$	in.	2.287	Drift at failure, $\Delta_{failure}$	in.	2.287
	mm	58.10		mm	58.10
Elastic stiffness, K_e @$0.4F_{peak}$	Kip/in.	25.251	Shear modulus, G @$0.4F_{peak}$	Kip/in.	25.251
	KN/mm	4.422		KN/mm	4.422
Work until failure	Kip·ft.	9.464	Work until failure per unit length	Kip·ft./ft.	1.183
	KN·m	12.831		KN·m/m	5.262
Load @ .32 in. (8.13 mm)	Kips	5.668	Unit load @ .32 in. (8.13 mm)	Kips/ft.	0.708
	KN	25.209		KN/m	10.338
Load @ .48 in. (12.19 mm)	Kips	6.844	Unit load @ .48 in. (12.19 mm)	Kips/ft.	0.855
	KN	30.441		KN/m	12.484
Load @ .96 in. (24.38 mm)	Kips	8.661	Unit load @ .96 in. (24.38 mm)	Kips/ft.	1.083
	KN	38.526		KN/m	15.800
Load @ 1.6 in. (40.64 mm)	Kips	9.846	Unit load @ 1.6 in. (40.64 mm)	Kips/ft.	1.231
	KN	43.793		KN/m	17.960
Ductility factor, μ		6.61	ζ_{eq} @v_{peak}		0.182

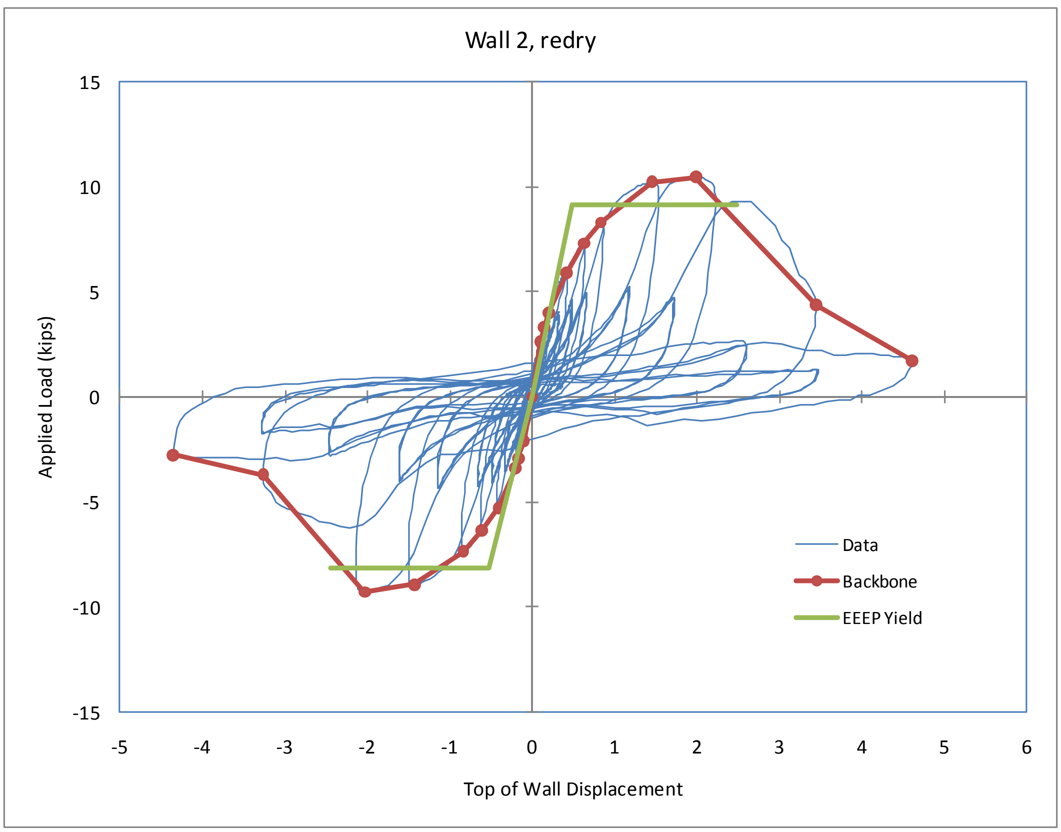
Specimen dry3	For total length	
dry 3	CUREE cyclic test	
Effective wall length	**96in.**	**2.44m**

cycle	avg. displacement		avg. load		work per cycle		cumulative work		cyclic stiffness		damping ratio	line number
initial	in.	mm	Kips	KN	Kip·ft.	KN·m	Kip·ft.	KN·m	Kip/in.	KN/mm		
	0	0	0	0	0	0	0	0				13
1	0.093	2.363	2.942	13.084	0.027	0.036	0.027	0.036	31.766	5.563	0.183	112
7	0.151	3.829	3.887	17.288	0.044	0.060	0.193	0.262	25.769	4.513	0.144	778
14	0.201	5.112	4.567	20.315	0.067	0.091	0.426	0.577	22.682	3.972	0.139	1555
21	0.403	10.225	6.441	28.648	0.227	0.308	0.887	1.202	15.989	2.800	0.167	2332
25	0.618	15.695	7.564	33.645	0.365	0.495	1.512	2.050	12.243	2.144	0.149	2776
29	0.836	21.228	8.306	36.947	0.483	0.654	2.382	3.230	9.941	1.741	0.133	3220
32	1.370	34.806	9.847	43.797	1.305	1.769	4.025	5.457	7.188	1.259	0.185	3554
35	1.920	48.759	9.859	43.854	1.784	2.419	6.436	8.726	5.140	0.900	0.180	3887
38	2.154	54.723	5.409	24.061	2.057	2.788	9.464	12.831	2.456	0.430	0.329	4221
41	1.793	45.531	1.416	6.297	1.034	1.402	11.389	15.440	-0.555	-0.097	2.624	4554

cycle	Negative stroke		Positive stroke		Negative stroke		Positive stroke		Area, Kip-in.		Unit load, KN/m	
initial	in.	Kips	in.	Kips	mm	KN	mm	KN	negative	positive	negative	positive
	0	0	0	0	0	0	0	0	0	0	0	0
1	-0.105	-3.226	0.081	2.657	-2.677	-14.349	2.050	11.819	0.170	0.107	-5.885	4.847
7	-0.156	-4.075	0.146	3.698	-3.960	-18.126	3.698	16.449	0.184	0.206	-7.434	6.746
14	-0.209	-4.799	0.194	4.335	-5.298	-21.347	4.925	19.282	0.234	0.194	-8.755	7.908
21	-0.410	-6.807	0.395	6.075	-10.411	-30.276	10.038	27.020	1.168	1.048	-12.417	11.081
25	-0.616	-7.932	0.620	7.197	-15.651	-35.280	15.738	32.010	1.520	1.489	-14.469	13.128
29	-0.831	-8.575	0.840	8.038	-21.112	-38.142	21.344	35.752	1.774	1.681	-15.642	14.662
32	-1.348	-9.876	1.393	9.817	-34.232	-43.928	35.380	43.667	4.765	4.933	-18.015	17.908
35	-1.859	-9.800	1.980	9.919	-47.224	-43.589	50.295	44.118	5.032	5.794	-17.876	18.093
38	-3.411	-0.510	3.378	3.289	-86.637	-2.269	85.806	14.631	7.999	9.233	-0.931	6.000
41	-4.479	-0.116	4.504	0.754	-113.756	-0.514	114.409	3.355	0.334	2.277	-0.211	1.376

Data analyzed by: Thomas D. Skaggs, Ph.D., P.E.





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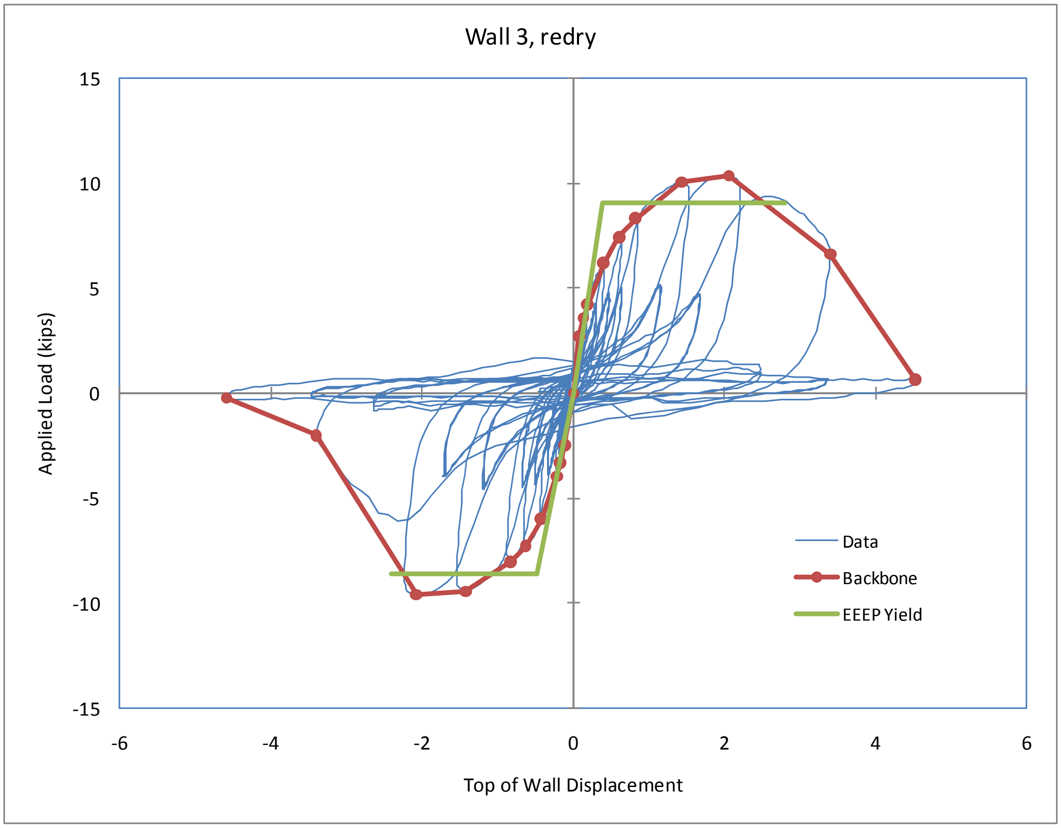

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Specimen Redry1	For total length		Specimen Redry1	Per unit length		Specimen Redry1	For total length	
Redry1	CUREE cyclic test		Redry1	CUREE cyclic test		Redry1	CUREE cyclic test	
Effective wall length	96in.	2.44m	Effective wall length	96in.	2.44m	Effective wall length	96in.	2.44m
Date: 7/11/2011	Time:	13:46	Date: 7/11/2011	Time:	13:46			

EEEP Parameters	units	initial	EEEP Parameters	units	initial
Peak load, F_{peak}	Kips	10.083	Peak unit load, v_{peak}	Kip/ft.	1.260
	KN	44.847		KN/m	18.392
Drift at peak load, Δ_{peak}	in.	2.390	Drift at capacity, Δ_{peak}	in.	2.390
	mm	60.70		mm	60.70
Yield load, F_{yield}	Kips	9.015	Yield unit load, v_{yield}	Kip/ft.	1.127
	KN	40.099		KN/m	16.445
Drift at yield load, Δ_{yield}	in.	0.539	Drift at yield load, Δ_{yield}	in.	0.539
	mm	13.69		mm	13.69
Proportional limit, $0.4F_{peak}$	Kips	4.033	Proportional limit, $0.4v_{peak}$	Kip/ft.	0.504
	KN	17.939		KN/m	7.357
Drift at prop. limit, $\Delta@0.4F_{peak}$	in.	0.241	Drift at prop. limit, $\Delta@0.4v_{peak}$	in.	0.241
	mm	6.12		mm	6.12
Failure load or $0.8F_{peak}$	Kips	8.066	Unit load at failure or $0.8v_{peak}$	Kip/ft.	1.008
	KN	35.878		KN/m	14.714
Drift at failure, $\Delta_{failure}$	in.	3.087	Drift at failure, $\Delta_{failure}$	in.	3.087
	mm	78.41		mm	78.41
Elastic stiffness, K_e @$0.4F_{peak}$	Kip/in.	16.762	Shear modulus, G @$0.4F_{peak}$	Kip/in.	16.762
	KN/mm	2.935		KN/mm	2.935
Work until failure	Kip·ft.	13.738	Work until failure per unit length	Kip·ft./ft.	1.717
	KN·m	18.625		KN·m/m	7.638
Load @ .32 in. (8.13 mm)	Kips	4.787	Unit load @ .32 in. (8.13 mm)	Kips/ft.	0.598
	KN	21.294		KN/m	8.733
Load @ .48 in. (12.19 mm)	Kips	6.045	Unit load @ .48 in. (12.19 mm)	Kips/ft.	0.756
	KN	26.887		KN/m	11.027
Load @ .96 in. (24.38 mm)	Kips	8.122	Unit load @ .96 in. (24.38 mm)	Kips/ft.	1.015
	KN	36.125		KN/m	14.815
Load @ 1.6 in. (40.64 mm)	Kips	9.702	Unit load @ 1.6 in. (40.64 mm)	Kips/ft.	1.213
	KN	43.154		KN/m	17.698
Ductility factor, μ		5.74	ζ_{eq} @v_{peak}		0.192

cycle	avg. displacement		avg. load		work per cycle		cumulative work		cyclic stiffness		damping	line
initial	in.	mm	Kips	KN	Kip·ft.	KN·m	Kip·ft.	KN·m	Kip/in.	KN/mm	ratio	number
	0	0	0	0	0	0	0	0				13
1	0.099	2.520	2.396	10.659	0.020	0.027	0.020	0.027	24.644	4.316	0.163	111
7	0.151	3.839	3.080	13.701	0.035	0.048	0.146	0.198	20.519	3.593	0.146	778
14	0.208	5.277	3.714	16.520	0.055	0.074	0.325	0.441	17.953	3.144	0.135	1556
21	0.412	10.471	5.674	25.237	0.185	0.251	0.689	0.934	13.773	2.412	0.151	2332
25	0.628	15.960	6.865	30.537	0.326	0.442	1.231	1.669	10.926	1.913	0.144	2777
29	0.839	21.311	7.755	34.494	0.451	0.611	2.023	2.742	9.243	1.619	0.132	3221
32	1.442	36.619	9.577	42.599	1.261	1.710	3.590	4.867	6.645	1.164	0.174	3554
35	2.033	51.627	10.039	44.654	1.768	2.397	5.977	8.103	4.938	0.865	0.165	3888
38	2.740	69.602	9.667	42.997	3.032	4.110	9.962	13.506	3.526	0.617	0.218	4221
41	3.183	80.843	4.149	18.454	2.217	3.006	13.738	18.625	1.304	0.228	0.321	4555

cycle	Negative stroke		Positive stroke		Negative stroke		Positive stroke		Area, Kip-in.		Unit load, KN/m	
initial	in.	Kips	in.	Kips	mm	KN	mm	KN	negative	positive	negative	positive
	0	0	0	0	0	0	0	0	0	0	0	0
1	-0.112	-2.359	0.086	2.434	-2.855	-10.494	2.184	10.825	0.133	0.105	-4.304	4.439
7	-0.160	-2.898	0.142	3.262	-4.064	-12.890	3.614	14.511	0.125	0.160	-5.286	5.951
14	-0.218	-3.595	0.197	3.833	-5.547	-15.991	5.006	17.048	0.190	0.194	-6.558	6.992
21	-0.420	-5.585	0.404	5.763	-10.678	-24.843	10.264	25.632	0.927	0.993	-10.188	10.512
25	-0.631	-6.837	0.626	6.894	-16.030	-30.410	15.890	30.664	1.309	1.402	-12.471	12.576
29	-0.840	-7.677	0.838	7.833	-21.344	-34.146	21.278	34.843	1.518	1.562	-14.003	14.289
32	-1.454	-9.402	1.429	9.752	-36.937	-41.820	36.302	43.378	5.242	5.201	-17.151	17.790
35	-2.020	-9.738	2.045	10.340	-51.303	-43.315	51.951	45.993	5.413	6.189	-17.764	18.862
38	-2.721	-8.906	2.760	10.427	-69.113	-39.615	70.091	46.380	6.537	7.416	-16.246	19.021
41	-4.464	-0.575	4.489	2.592	-113.383	-2.558	114.031	11.530	8.262	11.261	-1.049	4.728

Data analyzed by: Thomas D. Skaggs, Ph.D., P.E.

Specimen Redry2	For total length		Specimen Redry2	Per unit length	
Redry 2	CUREE cyclic test		Redry 2	CUREE cyclic test	
Effective wall length	96in.	2.44m	Effective wall length	96in.	2.44m
Date: 7/13/2011	Time:	11:21	Date: 7/13/2011	Time:	11:21
EEEP Parameters	**units**	**initial**	**EEEP Parameters**	**units**	**initial**
Peak load, F_{peak}	Kips	9.874	Peak unit load, v_{peak}	Kip/ft.	1.234
	KN	43.921		KN/m	18.012
Drift at peak load, Δ_{peak}	in.	2.008	Drift at capacity, Δ_{peak}	in.	2.008
	mm	51.00		mm	51.00
Yield load, F_{yield}	Kips	8.635	Yield unit load, v_{yield}	Kip/ft.	1.079
	KN	38.406		KN/m	15.751
Drift at yield load, Δ_{yield}	in.	0.500	Drift at yield load, Δ_{yield}	in.	0.500
	mm	12.71		mm	12.71
Proportional limit, $0.4F_{peak}$	Kips	3.950	Proportional limit, $0.4v_{peak}$	Kip/ft.	0.494
	KN	17.568		KN/m	7.205
Drift at prop. limit, $\Delta@0.4F_{peak}$	in.	0.229	Drift at prop. limit, $\Delta@0.4v_{peak}$	in.	0.229
	mm	5.81		mm	5.81
Failure load or $0.8F_{peak}$	Kips	7.899	Unit load at failure or $0.8v_{peak}$	Kip/ft.	0.987
	KN	35.137		KN/m	14.410
Drift at failure, $\Delta_{failure}$	in.	2.464	Drift at failure, $\Delta_{failure}$	in.	2.464
	mm	62.59		mm	62.59
Elastic stiffness, K_e $@0.4F_{peak}$	Kip/in.	17.338	Shear modulus, G $@0.4F_{peak}$	Kip/in.	17.338
	KN/mm	3.036		KN/mm	3.036
Work until failure	Kip·ft.	9.953	Work until failure per unit length	Kip·ft./ft.	1.244
	KN·m	13.494		KN·m/m	5.534
Load @ .32 in. (8.13 mm)	Kips	4.752	Unit load @ .32 in. (8.13 mm)	Kips/ft.	0.594
	KN	21.138		KN/m	8.669
Load @ .48 in. (12.19 mm)	Kips	5.985	Unit load @ .48 in. (12.19 mm)	Kips/ft.	0.748
	KN	26.619		KN/m	10.917
Load @ .96 in. (24.38 mm)	Kips	8.192	Unit load @ .96 in. (24.38 mm)	Kips/ft.	1.024
	KN	36.438		KN/m	14.943
Load @ 1.6 in. (40.64 mm)	Kips	9.666	Unit load @ 1.6 in. (40.64 mm)	Kips/ft.	1.208
	KN	42.993		KN/m	17.632
Ductility factor, μ		4.94	ζ_{eq} $@v_{peak}$		0.169

Specimen Redry2	For total length	
Redry 2	CUREE cyclic test	
Effective wall length	96in.	2.44m

cycle	avg. displacement		avg. load		work per cycle		cumulative work		cyclic stiffness		damping	line
initial	in.	mm	Kips	KN	Kip·ft.	KN·m	Kip·ft.	KN·m	Kip/in.	KN/mm	ratio	number
	0	0	0	0	0	0	0	0				13
1	0.096	2.427	2.356	10.480	0.020	0.027	0.020	0.027	24.819	4.346	0.168	110
7	0.157	3.976	3.120	13.877	0.037	0.050	0.156	0.211	20.197	3.537	0.146	778
14	0.198	5.020	3.674	16.343	0.055	0.075	0.344	0.467	18.617	3.260	0.145	1556
21	0.414	10.527	5.584	24.839	0.188	0.254	0.729	0.988	13.471	2.359	0.155	2332
25	0.616	15.658	6.823	30.350	0.320	0.433	1.284	1.741	11.063	1.937	0.145	2777
29	0.833	21.154	7.824	34.801	0.449	0.609	2.086	2.829	9.397	1.646	0.132	3221
32	1.442	36.619	9.585	42.634	1.260	1.708	3.671	4.977	6.646	1.164	0.174	3554
35	2.008	51.003	9.874	43.921	1.752	2.376	6.083	8.247	4.922	0.862	0.169	3887
38	2.381	60.485	7.779	34.600	2.826	3.831	9.953	13.494	3.237	0.567	0.287	4221
41	2.876	73.047	2.800	12.453	1.810	2.453	13.187	17.879	0.972	0.170	0.429	4555

cycle	Negative stroke		Positive stroke		Negative stroke		Positive stroke		Area, Kip-in.		Unit load, KN/m	
initial	in.	Kips	in.	Kips	mm	KN	mm	KN	negative	positive	negative	positive
	0	0	0	0	0	0	0	0	0	0	0	0
1	-0.100	-2.106	0.091	2.606	-2.532	-9.366	2.322	11.593	0.105	0.119	-3.841	4.754
7	-0.170	-2.923	0.143	3.316	-4.328	-13.003	3.625	14.751	0.178	0.152	-5.333	6.049
14	-0.201	-3.381	0.195	3.967	-5.098	-15.040	4.943	17.647	0.096	0.189	-6.168	7.237
21	-0.413	-5.276	0.416	5.893	-10.485	-23.469	10.569	26.210	0.918	1.092	-9.625	10.749
25	-0.611	-6.355	0.622	7.292	-15.524	-28.268	15.791	32.433	1.154	1.355	-11.593	13.301
29	-0.836	-7.360	0.829	8.288	-21.242	-32.736	21.067	36.866	1.544	1.618	-13.425	15.119
32	-1.434	-8.952	1.449	10.218	-36.431	-39.819	36.807	45.450	4.877	5.734	-16.330	18.639
35	-2.035	-9.302	1.981	10.446	-51.694	-41.376	50.312	46.465	5.485	5.494	-16.969	19.055
38	-3.264	-3.719	3.445	4.359	-82.901	-16.541	87.508	19.388	7.999	10.840	-6.783	7.951
41	-4.353	-2.768	4.598	1.710	-110.569	-12.312	116.789	7.604	3.533	3.498	-5.049	3.119

Data analyzed by: Thomas D. Skaggs, Ph.D., P.E.

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Specimen redry3	For total length	
redry3	CUREE cyclic test	
Effective wall length	96in.	2.44m
Date: 7/27/2011	Time:	09:45
EEEP Parameters	**units**	**initial**
Peak load, F_{peak}	Kips	9.976
	KN	44.375
Drift at peak load, Δ_{peak}	in.	2.065
	mm	52.44
Yield load, F_{yield}	Kips	8.828
	KN	39.266
Drift at yield load, Δ_{yield}	in.	0.435
	mm	11.06
Proportional limit, $0.4F_{peak}$	Kips	3.991
	KN	17.750
Drift at prop. limit, $\Delta@0.4F_{peak}$	in.	0.197
	mm	4.99
Failure load or $0.8F_{peak}$	Kips	7.981
	KN	35.500
Drift at failure, $\Delta_{failure}$	in.	2.605
	mm	66.16
Elastic stiffness, K_e $@0.4F_{peak}$	Kip/in.	20.538
	KN/mm	3.597
Work until failure	Kip·ft.	10.037
	KN·m	13.608
Load @ .32 in. (8.13 mm)	Kips	5.184
	KN	23.060
Load @ .48 in. (12.19 mm)	Kips	6.495
	KN	28.891
Load @ .96 in. (24.38 mm)	Kips	8.514
	KN	37.871
Load @ 1.6 in. (40.64 mm)	Kips	9.802
	KN	43.600
Ductility factor, μ		6.09

Specimen redry3	Per unit length	
redry3	CUREE cyclic test	
Effective wall length	96in.	2.44m
Date: 7/27/2011	Time:	09:45
EEEP Parameters	**units**	**initial**
Peak unit load, v_{peak}	Kip/ft.	1.247
	KN/m	18.198
Drift at capacity, Δ_{peak}	in.	2.065
	mm	52.44
Yield unit load, v_{yield}	Kip/ft.	1.103
	KN/m	16.103
Drift at yield load, Δ_{yield}	in.	0.435
	mm	11.06
Proportional limit, $0.4v_{peak}$	Kip/ft.	0.499
	KN/m	7.279
Drift at prop. limit, $\Delta@0.4v_{peak}$	in.	0.197
	mm	4.99
Unit load at failure or $0.8v_{peak}$	Kip/ft.	0.998
	KN/m	14.559
Drift at failure, $\Delta_{failure}$	in.	2.605
	mm	66.16
Shear modulus, G $@0.4F_{peak}$	Kip/in.	20.538
	KN/mm	3.597
Work until failure per unit length	Kip·ft./ft.	1.255
	KN·m/m	5.581
Unit load @ .32 in. (8.13 mm)	Kips/ft.	0.648
	KN/m	9.457
Unit load @ .48 in. (12.19 mm)	Kips/ft.	0.812
	KN/m	11.849
Unit load @ .96 in. (24.38 mm)	Kips/ft.	1.064
	KN/m	15.531
Unit load @ 1.6 in. (40.64 mm)	Kips/ft.	1.225
	KN/m	17.880
ζ_{eq} $@v_{peak}$		0.169

Specimen redry3	For total length	
redry3	CUREE cyclic test	
Effective wall length	96in.	2.44m

cycle	avg. displacement		avg. load		work per cycle		cumulative work		cyclic stiffness		damping ratio	line number
initial	in.	mm	Kips	KN	Kip·ft.	KN·m	Kip·ft.	KN·m	Kip/in.	KN/mm		
	0	0	0	0	0	0	0	0				13
1	0.095	2.418	2.587	11.509	0.021	0.029	0.021	0.029	28.792	5.042	0.168	108
7	0.153	3.885	3.449	15.343	0.039	0.053	0.163	0.221	23.165	4.057	0.141	778
14	0.205	5.203	4.097	18.222	0.057	0.078	0.359	0.486	20.236	3.544	0.131	1554
21	0.415	10.536	6.088	27.080	0.194	0.263	0.751	1.018	14.708	2.576	0.147	2330
25	0.619	15.712	7.369	32.778	0.337	0.457	1.314	1.782	11.923	2.088	0.141	2774
29	0.826	20.989	8.164	36.313	0.461	0.624	2.115	2.867	9.880	1.730	0.130	3218
32	1.428	36.271	9.736	43.307	1.304	1.768	3.741	5.072	6.819	1.194	0.179	3551
35	2.065	52.442	9.976	44.375	1.826	2.475	6.240	8.459	4.833	0.846	0.169	3885
38	2.417	61.384	7.724	34.357	2.781	3.770	10.037	13.608	3.174	0.556	0.282	4219
41	1.383	35.135	1.097	4.880	0.796	1.079	11.807	16.008	-0.591	-0.103	3.173	4552

cycle	Negative stroke		Positive stroke		Negative stroke		Positive stroke		Area, Kip-in.		Unit load, KN/m	
initial	in.	Kips	in.	Kips	mm	KN	mm	KN	negative	positive	negative	positive
	0	0	0	0	0	0	0	0	0	0	0	0
1	-0.116	-2.495	0.074	2.679	-2.951	-11.100	1.885	11.917	0.145	0.099	-4.552	4.887
7	-0.175	-3.330	0.131	3.568	-4.455	-14.814	3.315	15.871	0.172	0.176	-6.075	6.509
14	-0.224	-3.980	0.185	4.213	-5.700	-17.704	4.707	18.740	0.179	0.213	-7.260	7.685
21	-0.431	-5.991	0.399	6.186	-10.940	-26.647	10.132	27.514	1.028	1.111	-10.928	11.284
25	-0.634	-7.304	0.603	7.434	-16.109	-32.489	15.316	33.067	1.353	1.390	-13.324	13.561
29	-0.830	-8.019	0.823	8.309	-21.074	-35.668	20.904	36.958	1.498	1.732	-14.628	15.156
32	-1.433	-9.437	1.423	10.036	-36.393	-41.975	36.149	44.639	5.264	5.505	-17.214	18.307
35	-2.078	-9.605	2.052	10.348	-52.774	-42.723	52.111	46.028	6.140	6.405	-17.521	18.876
38	-3.409	-2.003	3.391	6.621	-86.581	-8.908	86.136	29.452	7.725	11.366	-3.653	12.078
41	-4.590	-0.234	4.522	0.627	-116.576	-1.043	114.869	2.791	1.321	4.100	-0.428	1.145

Data analyzed by: Thomas D. Skaggs, Ph.D., P.E.

Appendix D: Summary of Cyclic Properties (1 page)

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Cyclic test data from restrained SIPs, analyzed following ICC ES AC130 methodology

Wall Number	Wall Type (length)	Fastener Spacing	Center "stud"	ASD Design Value, plf [1]	ASD Design Deflection, inch (neg)	ASD Design Deflection, inch (pos)	Ultimate Deflection, inch (neg)	Ultimate Deflection, inch (pos)	Peak Load, plf (neg)	Peak Load, plf (pos)	Section 5.2.2 [2]	Section 5.2.3 [3] H	Section 5.2.4 [4]
Dry1	SIP Dry	8d common nail @ 6" oc	7/16" block spline	315	-0.094	0.074	-1.907	2.388	-1,151	1,171	25.6	0.022	3.69
Dry2				315	-0.091	0.066	-2.811	3.101	-1,260	1,263	37.6	0.031	4.00
Dry3				315	-0.082	0.077	-2.176	2.398	-1,234	1,240	28.8	0.024	3.93
Redry1	SIP Wet/Redry	8d common nail @ 6" oc	7/16" block spline	315	-0.127	0.092	-2.954	3.220	-1,217	1,303	28.3	0.032	4.00
Redry2				315	-0.136	0.088	-2.445	2.483	-1,163	1,306	22.0	0.026	3.92
Redry3				315	-0.118	0.070	-2.414	2.796	-1,201	1,293	27.8	0.027	3.96

[1] Underlying assumption from IRC.

[2] Ultimate deflection divided by deflection at ASD Design Value, criterion is >= 11

[3] Minimum post peak displacement, criterion >= 0.028H

[4] Ratio of peak strength to assigned ASD design load, criterion is between 2.5 and 5.0.

ICC ES AC130 Analysis based on mean values

Wall Type	ASD Design Value [1]	Design Defl	Ultimate Defl	Peak Load	Section 5.2.2 [2]	Section 5.2.3 [3] H	Section 5.2.4 [4]
Dry	315	0.081	2.464	1,220	30.7	0.026	3.87
Redry	315	0.105	2.719	1,247	26.0	0.028	3.96

Thomas D. Skaggs

Data analyzed by: Thomas D. Skaggs, Ph.D., P.E.

Appendix E: Photos (2 pages)

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Figure E1. APA Trademark on OSB facers.

Figure E2. Wall loaded in test rack for cyclic test, note cut-outs in OSB for electrical boxes.

Figure E3. Bottom plate detail, the 4-1/2" wide SIP wall sitting on top of a 2x6.

Figure E4. Typical ultimate failure mode of top plate coming unattached to wall studs.

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Figure E5. Typical failure mode of walls with a combination of nail head pullout, pull-through and nail withdrawal from wall perimeter, as well as top plate coming unattached to wall studs (Figure E4).	

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