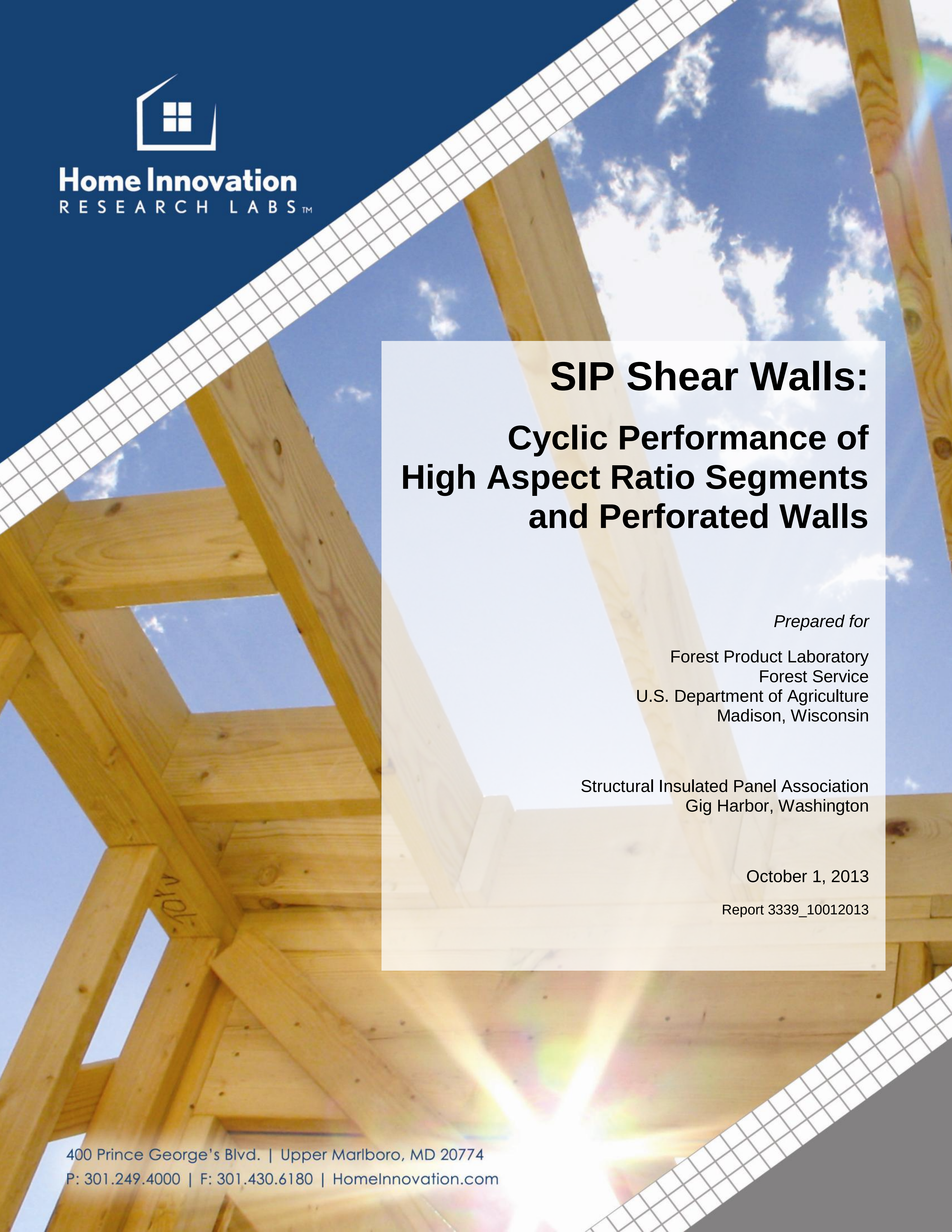

Home Innovation RESEARCH LABS™

SIP Shear Walls:

Cyclic Performance of High Aspect Ratio Segments and Perforated Walls

Prepared for

Forest Product Laboratory
Forest Service
U.S. Department of Agriculture
Madison, Wisconsin

Structural Insulated Panel Association
Gig Harbor, Washington

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400 Prince George's Blvd. | Upper Marlboro, MD 20774
P: 301.249.4000 | F: 301.430.6180 | HomeInnovation.com

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Introduction

This study addresses the aspect ratio limitations imposed on the SIP shear walls by product evaluation agencies. The NTA listing reports limits the aspect ratio to 2:1 for low seismic risk areas and 1:1 for high seismic risk areas. Many ICC-ES evaluation reports currently limit the aspect ratio for SIP shear walls to 1:1. These limitations have significant implications for engineered shear walls in nonresidential and residential construction where narrow aspect ratio segments are common as a result of doors and windows closely spaced or placed near building corners. With the increasing stringency of energy codes and the growing market demand for more energy efficient buildings, the SIP construction is well postured to increase its market. However, in some markets the aspect ratio limitation is a barrier to the wider adoption of SIP technology.

Objectives

The overall goal of this study is to develop performance test data on the response of SIP shear walls with high-aspect ratio segments. The results will provide the basis for developing design methodologies for future code, standard, or acceptance criteria proposals. The specific objectives of this study include:

1) Measure the performance of individual, fully-anchored shear segments with the following aspect ratios: 1:1, 2:1, 3:1, and 4:1.

2) Conduct a preliminary evaluation of the applicability of the perforated shear wall (PSW) method to SIP shear walls based on an initial limited set of perforated shear walls with high aspect ratio segments.

Background

Kermani and Hairstans, 2006

This research focused on the performance of 8 foot by 8 foot SIP wall systems with and without openings. Opening sizes ranged between 6% and 65% of the wall specimen area. Segment aspect ratio varied from 1:1 to 8:1. The wall specimens were constructed with (2) panels, spliced with a 2x4 lumber spline. Fastening of the panels to the perimeter boundary members was achieved with 1.38" long by 0.104" diameter screws at approximately 10 inches on center. Loading was applied monotonically, and each type of wall configuration was tested under two separate conditions; the first condition was without any vertical load applied, and the second was with a 700 lb/ft gravity load along the top of the specimens. For walls without openings, the peak shear load ranged between 320 lb/ft for unrestrained walls to 780 lb/ft for walls restrained with vertical load. For walls with openings, the research confirmed that capacity followed the general trend of the PSW method.

Jamison, 1997

Testing by Jamison was conducted as part of a master's thesis research program and included testing of 8 foot by 8 foot wall specimens with various boundary and anchorage detailing. The panels used a 7/16" OSB facing on one side and 1/2" drywall facing on the other. Nominal 2x4 lumber and 1/2 inch OSB block spline connections were tested. The tested end-wall boundary conditions included 1x4 lumber, 2x4 lumber, and 1/2 inch OSB surface splines. One configuration also included a double 2x4 bottom plate member. Fastening of the panels to the perimeter boundary and splice members was with 1-5/8 inch drywall screws spaced at 6 inches on center and construction adhesive. Specimens were tested monotonically or cyclically without vertical loading. Only one of the five configurations included end-wall hold-down anchors. Peak shear loads for the monotonically tested specimens ranged between 330 lb/ft and 880 lb/ft, with the specimen with hold-down anchors achieving the greatest capacity. Cyclic testing of the same configurations resulted in peak shear loads ranging between 320 lb/ft and 870 lb/ft.

APA 2010

The APA report summarizes testing of a single 8 foot by 8 foot SIP wall configuration subjected to various types of boundary restraint. The tested specimens were constructed with two panels, spliced together with an OSB box spline and attached to the boundary and spline members with 8d common nails spaced at 6 inches on center. The following configurations were tested monotonically: (1) only E72 type hold-downs with facers unrestrained from rotation, (2) E72 type hold-downs and 2x6 top and bottom cap plates restraining facer panel edge rotation, or (3) Simpson end-wall hold-downs, 2x6 cap plates and additional 3,200 lb/ft gravity load applied. The respective peak loads were 1,038 lb/ft, 1,582 lb/ft, and 2,120 lb/ft showing that facer bearing and gravity load contribute significantly to the wall's capacity. Cyclic testing was conducted on walls with only Simpson hold-downs and 2x6 plate caps without gravity load with the walls reaching an average peak load of 1,178 lb/ft, indicating a substantial reduction in capacity due to the cyclic protocol (however, out of the three tests, at least in two specimens the failure was at holddown fasteners or post not at the spline as with the monotonic tests).

Sugiyama and Tasumura, 1984; Sugiyama and Matsumoto, 1996

Testing conducted by Sugiyama and Yasumura studied one-third scale monotonic racking tests of wood stud, plywood sheathed shear walls with openings. The researchers defined the sheathing ratio (equation 1), r, to classify walls based on the amount of openings and the empirical relationship to strength and stiffness.

$$r = \frac{1}{1 + \frac{A_0}{H \Sigma L_i}} \qquad \textbf{(1)}$$

Where:

A_0 = Total area of openings;
H = Height of the wall; and,
ΣL_i = Summation of length of a full height wall segments.

Sugiyama and Matsumoto determined and empirical equation to relate shear capacity and sheathing area ratio, based on scaled tests. They determined an empirical equation that related the ratio (equation 2), F, of the shear load for a wall with openings to the shear load of a fully sheathed wall at shear deformation angle of 1-100 radians for ultimate capacity.

$$F = \frac{r}{3 - 2r} \qquad \textbf{(2)}$$

This method was referred to as the perforated shear wall (PSW) method. The method has since been adopted into the design provisions for wood shear walls published by the American Wood Council (Special Design Provisions for Wind and Seismic, 2012) and referenced in model building codes.

Manufacturer's Evaluation Reports Data

Table 1 below presents a summary of published allowable shear wall capacities obtained from ICC-ES Evaluation Reports (ESR) for several SIP manufacturers and NTA SIPA Listing Report. The summary includes allowable capacities as well as fastening schedules and boundary member lumber requirements.

Table 1. Manufacturer's Shear Wall Capacities

ESR # / NTA # [A]	Manufacturer	Allowable Shear Capacity (plf)	Fastening Detail / Lumber SG[B]
ICC-ES ESR 1882	Premier Sips by INSULFOAM	300	Nails at 6" oc / 0.50 SG lumber
		600	Nails at perimeter at 4" oc & screws at splice at 4" oc / 0.50 SG lumber
ICC-ES ESR 1138	Precision Panel Structures	170	Nails at 4" oc / 0.50 SG lumber
ICC-ES ESR 1295	PFB America Corporation	366-639	Nails at 6”-3” oc / 0.42 SG lumber
ICC-ES ESR 1802	Korwall	180	Staples at 4" oc / 0.55 SG lumber
ICC-ES ESR 2139	Stress Panel Manufactures	130	Nails or staples at 6" oc / 0.50 SG lumber
ICC-ES ESR 2233	R-Control	335-920	Nails at 6"-2” oc / 0.42 SG lumber
NTA SIPA120908-10	Listed SIPA members	380-900	Nails at 6"-3” oc / 0.42 SG lumber
NTA PRS032808-3	Insulfoam, a Carlisle Company	360-920	Nails at 6"-2” oc / 0.50 SG lumber
NTA Assembly Report: AFM031809-18	AFM Corporation	920	Nails at 2” oc / 0.50 SG lumber

[A] ICC-ES reports can be downloaded from www.icc-es.org. NTA reports can be downloaded from www.ntainc.com.
[B] SG = specific gravity.

Test Plan and Apparatus

Testing was conducted at the Home Innovation Research Labs in Upper Marlboro, MD in the first quarter of 2013. Testing was conducted in accordance with general provisions of ASTM 2126-11 Standard Test Methods for Cyclic (Reversed) Load Test for Shear Resistance of Walls for Buildings (ASTM International, 2011). Tables 2 and 3 provide the test matrix including detailed information on each wall configuration for walls without and with perforations, respectively.

Table 2. Test Matrix for Walls without Openings

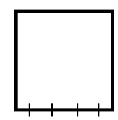
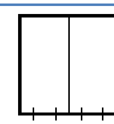
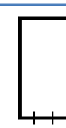
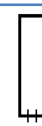
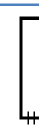
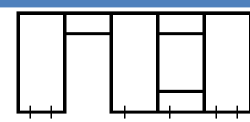
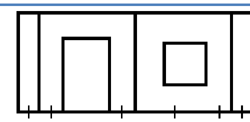
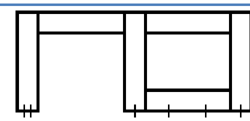
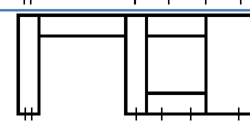
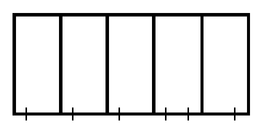
Config.	Segment or Wall	Specimen Width/Height	Segment Aspect Ratio	Overturning restraint	Protocol	Sample Size	Diagram	Purpose	SIP Panel Width (ft)	Bolt Locations (inches from left edge)
1M	Segment	8ft / 8ft	1:1	Holddown at wall end only	Monotonic	1		Provide baseline performance under monotonic loading and to establish delta for the CUREE protocol	8	12,36,60,84
1_{SPL}C	Segment	8ft / 8ft	1:1	Holddown at wall end only	Cyclic CUREE	1		Provide baseline performance under cyclic loading for a "spline" condition	4,4	12,36,60,84
2	Segment	4ft / 8ft	2:1	Holddown at wall end only	Cyclic CUREE	2		Evaluate 2:1 aspect ratio	4	12,36
3	Segment	2.67ft / 8ft	3:1	Holddown at wall end only	Cyclic CUREE	2		Evaluate 3:1 aspect ratio	2.67	8,24
4	Segment	2ft / 8ft	4:1	Holddown at wall end only	Cyclic CUREE	2		Evaluate 4:1 aspect ratio	2	8,16

Table 3. Test Matrix for Walls with Openings

Config.	Segment or Wall	Specimen Width/ Height	Segment Aspect Ratio	Overturning restraint	Protocol	Sample Size	Diagram	Purpose	SIP Panel Width (ft)	Bolt Locations (inches from left edge)
5	Wall – Splice Joints	20ft / 8ft	All 2:1	Holddown at wall end only	Cyclic CUREE	1		Evaluate wall with openings, all segments 2:1	4, 4, 4, 4, 4	12,36,108, 156,204,228
6	Wall – Cut-out openings	20ft / 8ft	All 2:1	Holddown at wall end only	Cyclic CUREE	1		Same openings as (5) but with continuous panel joints at openings	2, 8, 8, 2	12,36,108, 156,204,228
7	Wall – Splice Joints	20ft / 8ft	All 4:1	Holddown at wall end only	Cyclic CUREE	1		Evaluate wall with openings, all segments 4:1	2, 7, 2, 7, 2	8,16,120, 156,192,228
8	Wall – Splice Joints	20ft / 8ft	2:1 and 4:1	Holddown at wall end only	Cyclic CUREE	1		Evaluate wall with segments with different aspect ratios	2, 7, 2, 5, 4	8,16,120, 156,180,228
9	Wall – Splice Joints	20ft / 8ft	0.4:1	Holddown at wall end only	Cyclic CUREE	1		Evaluate the impact of multiple spline joints on the performance of a wall without openings	4, 4, 4, 4, 4	12,60,108, 156,180,228

Thirteen tests in total were conducted using a racking shear testing apparatus controlled via a computer-based system. Instrument readings including load and deformation measurements were recorded using a computer-based data acquisition system (see Figure 1 for a schematic of the test setup and Figure 2 for a photo of Configuration 1M specimen).

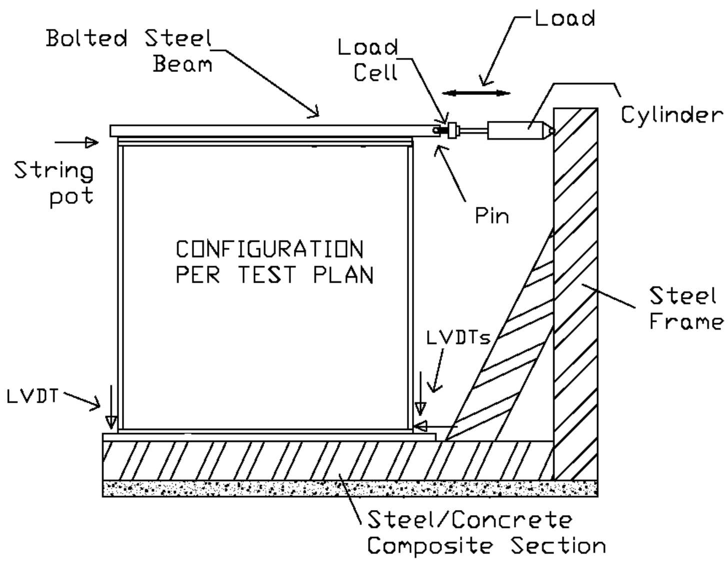


Figure 1. Shear Wall Test Setup

Figure 2. Shear Wall Specimen (Configuration 1M)

The load-deformation relationship from the monotonic test (Configuration 1M) was used to determine the reference deformation (Δ) for the cyclic CUREE protocol in accordance with ASTM 2126-11 Test Method C. The reference deformation of 1.6 inches was used in all cyclic tests. The cyclic tests were conducted by displacing the top of the specimen in accordance with the CUREE cyclic protocol (Figure 3) (Method C, ASTM E 2126) at a constant frequency of motion of 0.2 Hz (5 seconds per cycle). The hydraulic actuator has a total stroke of 12 inches with the maximum excursion set at 5.75 inches. The hydraulic cylinder was attached to the load beam using a 2 inch pin. A sampling rate of 20 Hz was used such that 100 data points were recorded for each cycle.

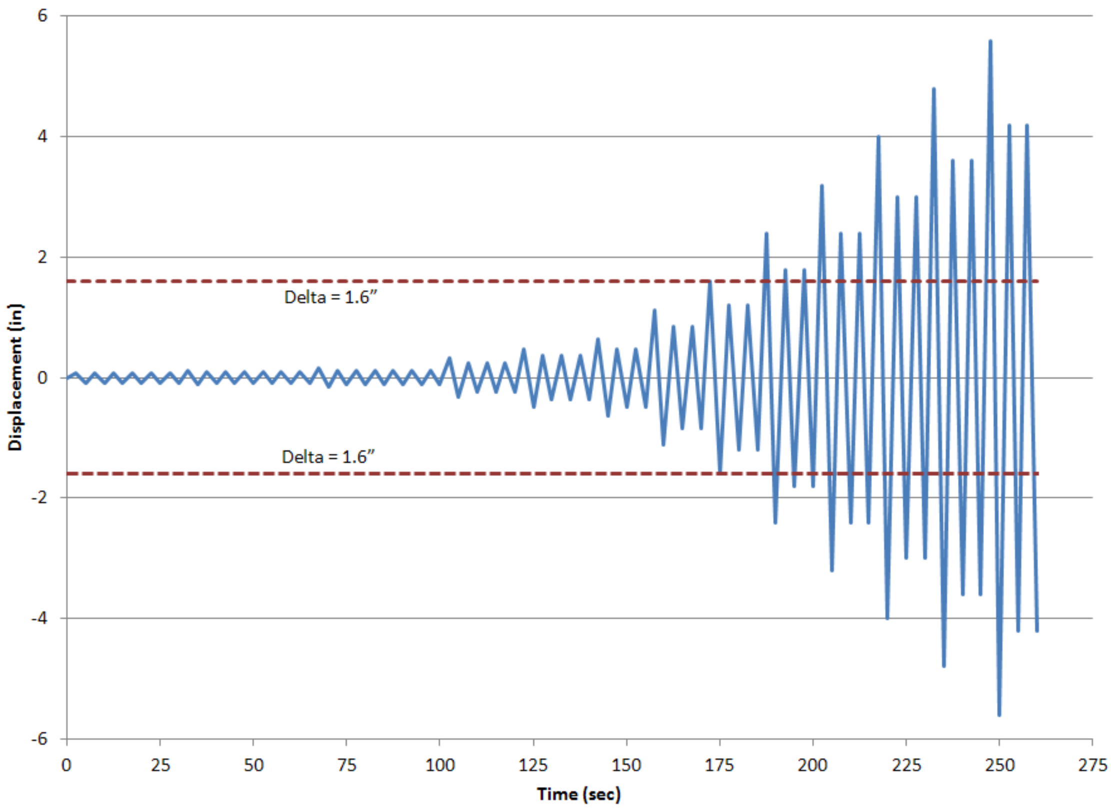


Figure 3. CUREE Protocol

The hydraulic actuator motion was applied using 4-inch by 4-inch by 0.25-inch walled steel distribution beam (moment of inertia of EI=226,200,000 lb-in^2) lag-bolted through a 2x6 spacer and the 2x6 top plate with 5/8-inch diameter 8-inch long bolts. The spacer was installed in such a manner that the wall panel skins were not allowed to bear on the spacer (the sheathing was able to rotate at the top plate without bearing restraint by framing members, spacer or load distribution beam). The out-of-plane deformations were restrained by a set of rollers located on the side of the load beam.

The load was measured using an electronic load cell, with a capacity of 50,000 lbs, located between the cylinder and the steel distribution beam. The following deformations were measured using a string potentiometer and Linear Variable Differential Transformers (LVDT):

1. Displacement of the top plate relative to the setup base
2. Bottom plate slip relative to the setup base
3. Bottom plate slip next to a doorway relative to the 2x8 sill plate (if applicable)
4. Compression and uplift at the specimen corner stud relative to the setup base
5. Compression and uplift at the jack stud inside a doorway relative to the 2x8 sill plate (if applicable)

Specimen Construction

The SIP panels were supplied by a local SIP manufacturer. Table 4 summarizes the materials and construction details and Table 5 summarizes the fastening schedule used in the construction of the test walls.

Table 4. Construction Materials and Details

Material	Details
Wall Height:	8'
Wall Width:	Varies according to test matrix (Tables 2 and 3)
Openings:	Door Height: 6'-8" Door Width: varies to achieve segment aspect ratios per test matrix Windows Height: 5' Window width: varies to achieve segment aspect ratios per test matrix
Wall Panels:	6.5" thick SIP panels; width varies to provide full segment aspect ratios per test matrix
Block Spline:	5.5” thick by 3” wide SIP block used for connecting SIP panels
Framing Lumber:	Nominal 2x6 Spruce-Pine-Fir (SPF) #2 grade
Sill Plate:	Nominal 2x8 Southern Yellow Pine (SYP) lumber
Holddown:	Simpson HDU11 raised 1 inch above bottom plate fastened with (30) SDS25212-R25 screws
Anchor Bolts:	5/8-inch diameter bolts with Simpson Strong-Tie BP5/8 – 3 plate washers spaced a maximum of 48 inches on center and located at 12 inches from corners. For 32-inch-wide walls, anchor bolts located at quarter points, i.e., 8 inches from corners. For 24-inch-wide walls, anchor bolts located at third points, i.e., 8 inches from corners.
Sheathing Fasteners:	8d pneumatic (2-3/8"x0.113") nails with full round head
Framing Fasteners:	16d pneumatic (3.25"x0.131") nails with full round head
Interior Finish:	None (no gypsum installed)

Table 5. Fastener Schedule

Connection	Fastener	Spacing
Panel sheathing to boundary framing	8d pneumatic	4 inches on center
Panel sheathing at spline	8d pneumatic	4 inches on center
Top/bottom plate to stud (end nailed)	(2) 16d pneumatic	Per connection
Holddown Bracket to end stud	(30) Simpson Strong-Tie SDS25212-R25 Screws	Per holddown
Double studs (face nailed)	(2) 16d pneumatic	16 inches on center
Top Plate to Spacer	(2) 16d pneumatic	6 inches on center

All specimens were 8-feet tall and ranged in length from 2 feet to 20 feet. Each wall specimen was constructed on the laboratory floor adjacent to the test setup and lifted in place with a crane using the loading beam. Temporary bracing was used as needed to ensure specimen integrity during installation in the setup. In 20-foot walls, splice joints in the top plate/spacer were offset a minimum 24 inches. Panel joints were constructed using block splines in accordance with Figure 4.

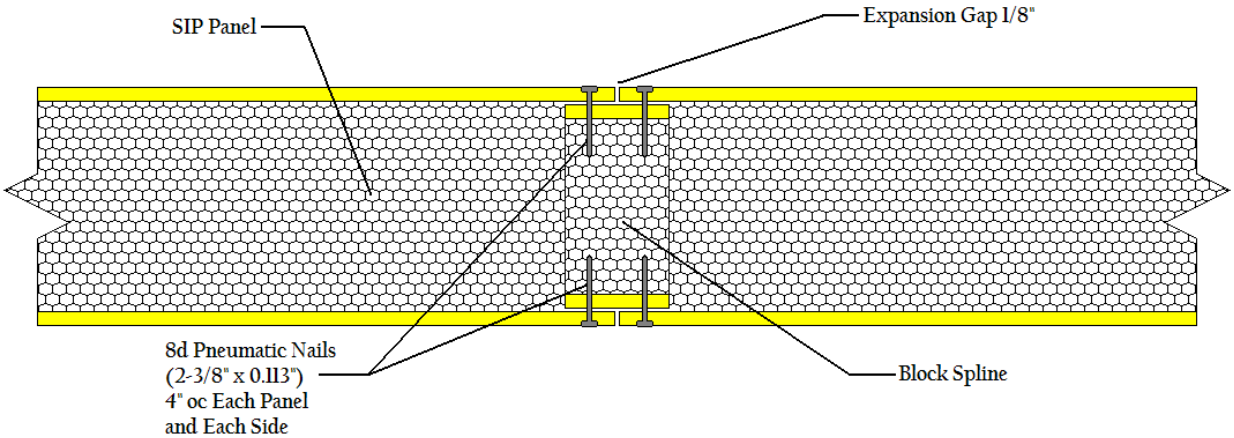


Figure 4. SIP Spline Detail

All boundary members consisted of 2x6 nominal framing lumber inset into the foam core between the OSB facings of the SIP panel. Single framing members were used for top and bottom plates. Double–stud posts were used at walls' ends. Single studs were used at cut-out openings and double studs were used with openings framed with individual header panels (one stud inserted into the full-height panel and one jack stud supporting the header panel). Double studs were nailed together using two 16d pneumatic nails every 16 inches. Wall openings in configurations 5, 7, and 8 were constructed in accordance to Figure 5.

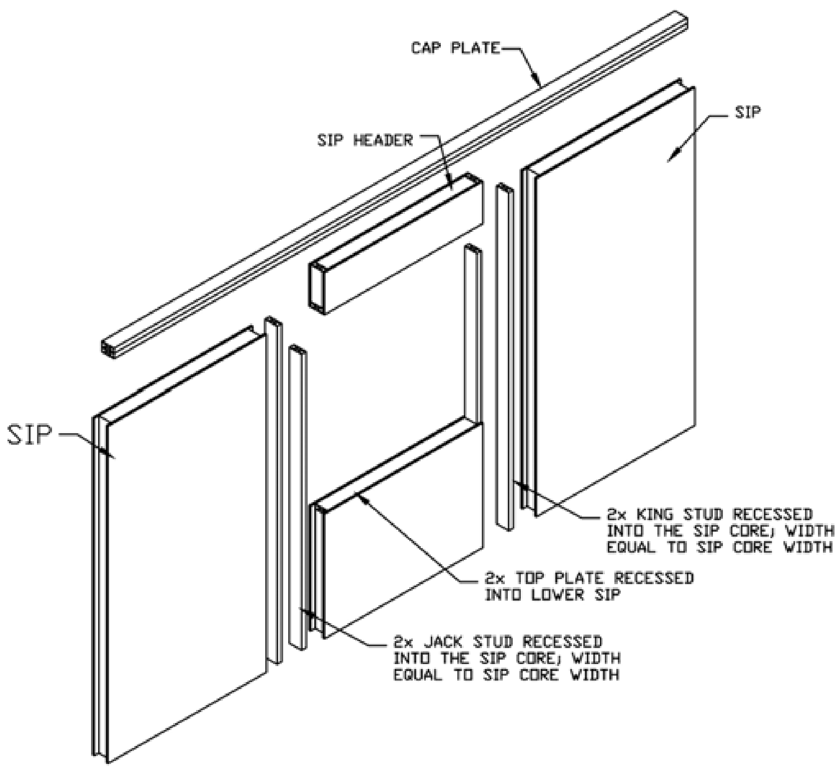


Figure 5. Segmented SIP Header Detail for Configurations 5, 7, and 8

The wall openings in configuration 6 were constructed in accordance to Figure 6.

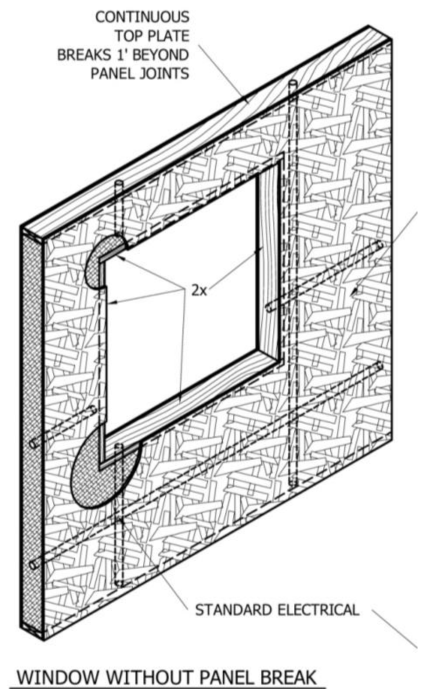


Figure 6. Continuous SIP Header Detail for Configuration 6

The bottom plate of the wall was placed on top of a preservative-treated 2x8 SYP sill plate and anchored down to the test setup using 5/8-inch diameter bolts with a 3-inch by 3-inch by 0.24-inch-thick Simpson Strong-Tie BP5/8 – 3 plate washers (Figure 7). The anchor bolts were tightened prior to installing the wall in the test frame. All anchor bolts and holddown bolts were tightened to a 1/8 turn past a hand-tight fit.

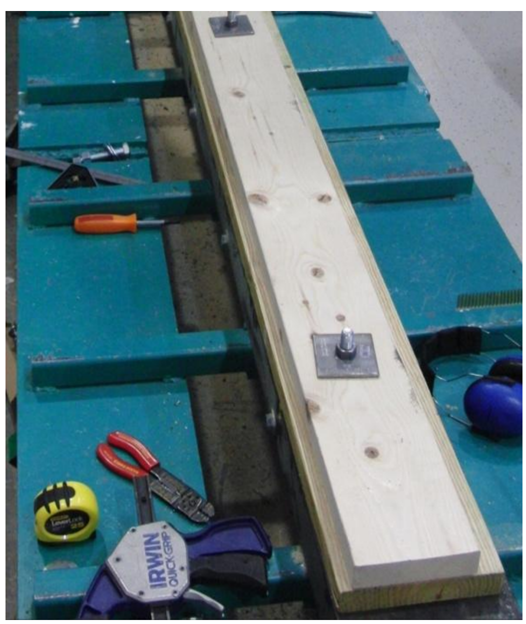


Figure 7. 2x6 Bottom Plate and 2x8 Sill Plate Bolted to Setup Base

The wall specimen was placed on top of the bottom plate such that the OSB facings of the SIP panels rested on the sill plate (Figure 8). The facings were nailed to the bottom plate in accordance with the sheathing nailing schedule (8d pneumatic nails at 4 inches on center).

Figure 8. OSB Facing Resting on Sill Plate

Material properties for framing lumber, SIP OSB panels, and SIP EPS core foam used in the manufacturing the shear wall test specimens were measured at the Home Innovation Research Labs (Table 6). EPS foam core material and OSB facings meet the minimum requirements of the 2012 International Residential Code (IRC) for materials used in SIPs (2012 IRC Section R613.3) and ANSI/APA PRS 610.1-2013. The OSB properties are higher than the minimum specification values required by the IRC. Because the objective of this study is to establish trends rather than establish minimum design values, using SIP panels that potentially have higher capacities will result in conservative conclusions and generalizations.

Table 6. Material Properties

SIP EPS Foam Core Properties	
Density (lbs/ft^3)	1.1
Compression Strength @ 10% Strain (psi)	15.8
Tensile Strength (psi)	30.7
Flexural Strength (psi)	29.1
OSB Facing Properties	
Specific Gravity	0.71
Parallel Stiffness (E) (lbs-in^2/ft)	93,714
Perpendicular Stiffness(E) (lbs-in^2/ft)	37,878
Parallel Strength (lbs-in/ft)	1,770
Perpendicular Strength (lbs-in/ft)	1,188
Framing	
Specific Gravity	0.40
Moisture content	9-12%

Results

General

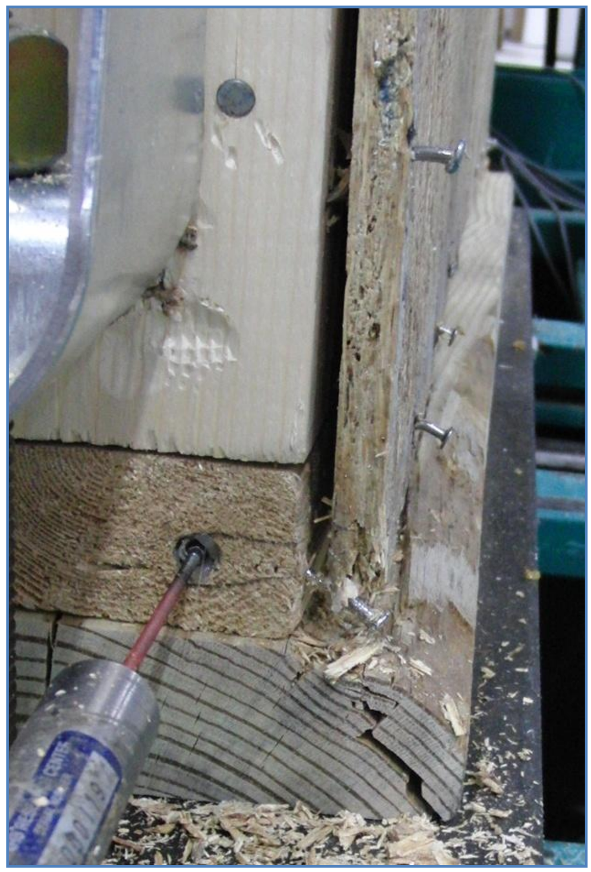
This section summarizes results of testing and analysis including observed failure modes, performance of walls without openings, and performance of walls with openings. In accordance with ASTM E2126, performance parameters for all cyclic tests were derived as an arithmetic average of the positive and negative envelope curves. The reported performance parameters include peak load, unit shear, shear stiffness at 0.4 peak load, unit shear stiffness at 0.4 peak load, and deflection at peak load. The PSW method is used to analyze walls with openings.

Tables 7 and 8 summarize the results for walls without openings and walls with openings, respectively. Appendix A provides load-deformation curves for all tests.

Failure Modes

The primary failure modes included separation of the wall top plate from the SIP panel, degradation of the sheathing nail connections, and crushing of the sill plate by the OSB facings (see Figure 9).

(a) Separation of top plate from OSB facings



(b) Crushing of the sill plate by the OSB facings

Figure 9. Typical Failure Modes

Rotation of the individual SIP panels relative to adjacent panels and/or the set-up was observed for all specimens leading to either opening of a gap between the adjacent segments or in some case a complete failure of the fasteners at the spline (Figure 10).

Figure 10. Rotation of Individual SIP Panels

For walls with perforations, stress concentration at the openings' corners lead to degradation of the connections between panels for walls framed with separate header panels (Configurations 5, 7, 8 - Figure 11) or cracking of the OSB facings in walls framed with SIPs panels with cutout openings (Configuration 6 – Figure 12). It should be noted that the separate header SIP panels were not directly attached to the framing of the adjacent SIP full-height panels. This configuration was tested to evaluate the lowest performance boundary.

Figure 11. Segment Separated from Header

Figure 12. Configuration 6 Cracking of OSB Skins (black lines indicate location of cracks)

Configuration 4 specimens (single 4:1 aspect ratio panels) were the only walls to not experience a failure leading to a significant drop in resistance. Although the top plate did begin to separate from the SIP panel, the walls survived the full deformation profile without a catastrophic failure.

Walls without Openings

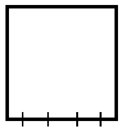
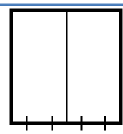
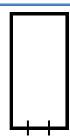
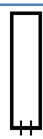
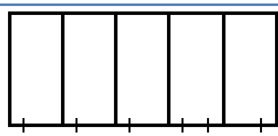
Table 7 summarizes results for walls without openings. The unit shear capacity ranges from 1,400 lb/ft to over 2,100 lb/ft. Both the unit shear capacity and unit shear stiffness show a strong dependency on the wall's aspect ratio. However, different trends are observed for unit capacity and unit stiffness. The unit shear capacity follows a "bell" curve with the top of the "bell" associated with the 4-foot single-panel specimen as shown in Figure 13. The "bell" trend is a function of two competing response mechanisms driving the performance of the wall. The reduction in unit shear capacity for longer walls with multiple SIP panels (Configurations 1_{spl}C and 9) – the left side of the "bell" – is associated with the spline connections between the SIP panels that are weaker than a connection directly to framing members. For a 20-foot long wall (Configuration 9) with a total of four spline joints, a reduction of 25 percent was observed relative to the 8-foot long wall (Configuration 1_{SPL}C) with one spline joint and 32 percent relative to the 4-foot long wall (Configuration 2) without spline joints.

The reduction in unit shear for high aspect ratio walls – the right side of the "bell" – is associated with the typical performance of narrow segments that is increasingly dominated by the uplift and bending components of the response. Using a 4-foot long wall (Configuration 2) as a baseline, the 2.67-foot wall shows a 10 percent decrease and the 2-foot wall shows a 16 percent decrease in unit shear strength. If an 8-foot wall is used as a baseline (Configuration 1_{SPL}C) which is a typical practice for light-frame walls, the 2.67-foot wall shows no decrease and the 2-foot wall shows an 8 percent decrease in unit shear strength.

As a general observation for establishing design values and guidance, the unit shear reduction due to the high aspect ratio effects is less than the reduction due to the spline joint.

The unit shear stiffness followed a general trend of a reduction in stiffness with increasing aspect ratio as shown in Figure 14. Configuration 9 showed the highest stiffness with any potential impact of the spline joints on the stiffness of the panel to panel connection outweighed by the increase due to the wall length. Configurations 1_{spl}C and 2 exhibited comparable stiffness, again suggesting that any potential reduction due to the higher aspect ratio for Configuration 2 was offset by the attachment of the SIP facings directly to framing members in lieu of the OSB spline. Further increase in aspect ratio for Configurations 3 and 4 resulted in a 20 percent and 33 percent reduction in stiffness, respectively.

Table 7. Summary of Results for Walls without Openings

Config.	Diagram	Specimen Width/Height	Aspect Ratio	Sample #	Peak Load (lbs)	Unit Shear (lbs/ft)	Stiffness @0.4P_{load} (lbs/in)	Unit Stiffness @0.4P_{load} (lbs/in/ft)	Deflection @ Peak Load (in)
1M		8ft / 8ft	1:1	1	14,297	1,787	11,828	1,478	2.14
1_{SPL}C		8ft / 8ft	1:1	1	14,791	1,849	9,976	1,247	2.63
2		4ft / 8ft	2:1	1	7,681	1,920	4,746	1,186	2.76
				2	8,660	2,165	5,049	1,262	2.84
3		2.67ft / 8ft	3:1	1	4,862	1,821	2,312	866	3.61
				2	4,979	1,865	2,824	1,058	3.63
4		2ft / 8ft	4:1	1	3,432	1,716	1,479	739	5.20
				2	3,402	1,701	1,732	866	4.25
9		8ft / 20ft	0.4:1	1	27,875	1,394	32,173	1,608	2.23

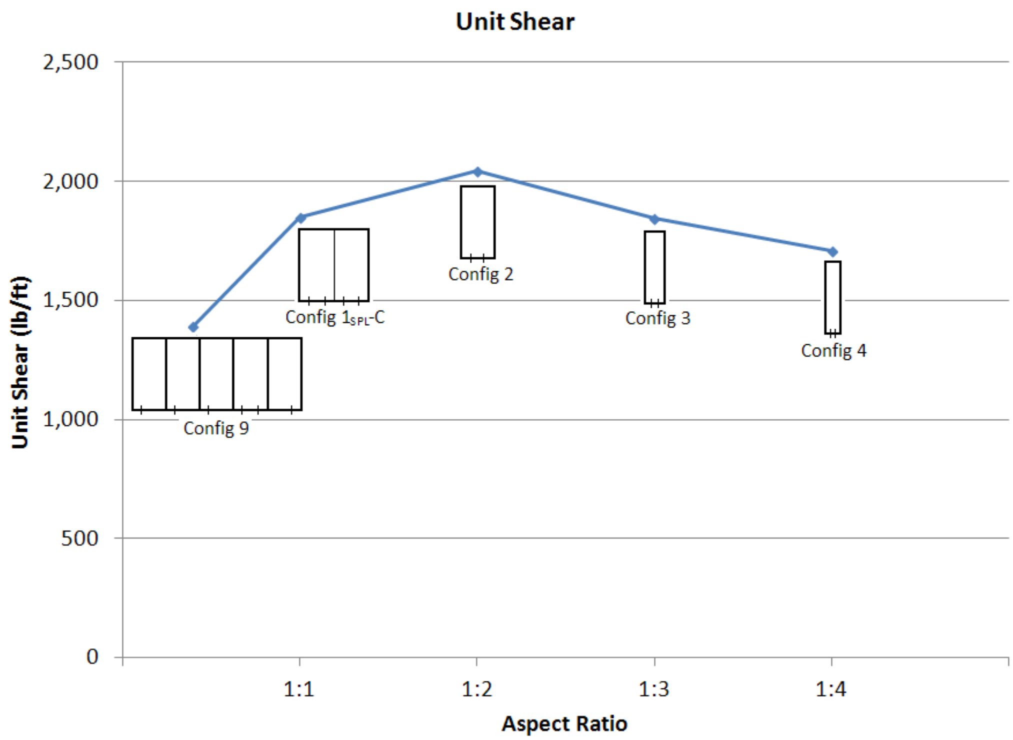


Figure 13. Unit Shear

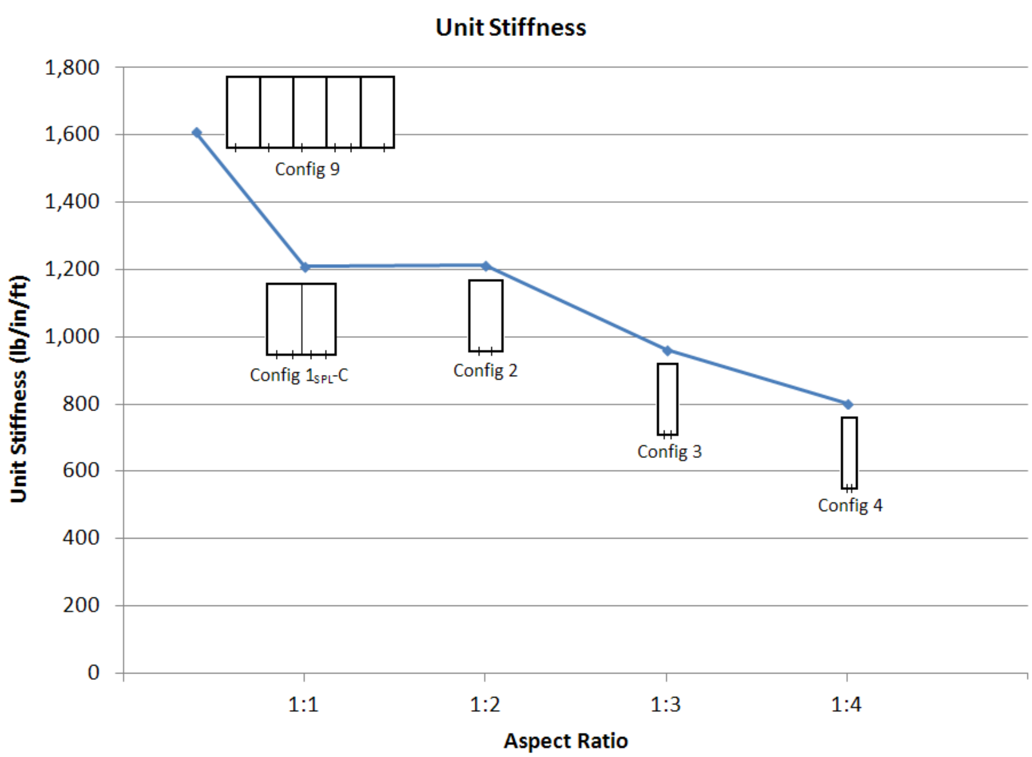


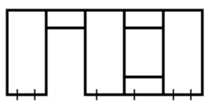
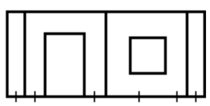
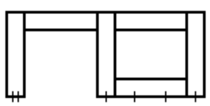
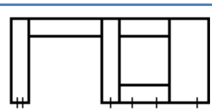
Figure 14. Unit Shear Stiffness

Walls with Openings (Perforated Walls)

Table 8 summarizes results for walls with openings. The perforated shear wall (PSW) method is used to evaluate peak load and stiffness at 0.4 peak load. Because unit shear and unit shear stiffness for fully anchored SIP walls depend on the wall length, the PSW method was used with Configurations $1_{SPL}C$ and 9 as baseline for comparison purposes. Figures 15-16 and Figures 17-18 graphically show the predictive power of the PSW method for SIP shear walls using the two respective baselines. The test results indicate that the SIP shear walls closely follow the overall PSW method trend for both load and stiffness. With exception of Configuration 5, all wall specimens exceeded the PSW method predictions for both load and stiffness criteria. Configuration 5 peak load was 6.5 percent below the predicted PSW value for the Configuration 1SPL-C baseline; Configuration 5 stiffness was 4 percent below the predicted PSW value for the Configuration 9 baseline. In Configuration 5, 7, and 8 specimens, the header panels were not directly attached to the adjacent full-height panels in order to simulate a low-bound condition (the OSB facings of the header panels were nailed to the top plate and bottom plate of the header was toe-nailed to the supporting jack studs). The header panels separated from the adjacent panel during the test as shown in Figures 11 and 19.

Configuration 6 with cutout openings shows significantly higher stiffness than Configuration 5 that uses spline joints at the window panels (25.5 Kips/in/lb vs. 13.7 Kips/in/lb). Similarly, Configuration 6 unit shear stiffness is significantly higher than the PSW method prediction. This observation indicates that the construction method that uses openings cutout from a panel results in increased wall stiffness compared to the practice of constructing openings with individual panel headers. This increase in stiffness does not correspond to a comparable increase in strength (17.9 Kips vs. 15.6 Kips), likely due to a failure mode change for Configuration 6 that associated with the facings cracking at window corners.

Table 8. Summary of Results for Walls with Openings

Config.	Diagram	Specimen Width/ Height	Segment Aspect Ratio	Calculated Characteristics Perforated Shear Wall (PSW) Method: Sheathing Ratio, r	PSW Ratio, F	Peak Load[1] (lb) / Stiffness[A] (lb/in)	Peak Load[2] (lb) / Stiffness[B] (lb/in)	Measured Characteristcis: Peak Load (lb) / Stiffness @0.4P_{load} (lb/in)	PSW Ratio, F: Baseline 1[A]	PSW Ratio, F: Baseline 2[B]	Deflection @ Peak Load (in)
5		20ft / 8ft	2:1	0.71	0.44	16,435 lb	12,389 lb	-15,362 lb	0.42[C]	0.55	1.83
						11,084 lb/in	14,299 lb/in	13,731 lb/in	0.55	0.43[C]	
6		20ft / 8ft	2:1	0.71	0.44	16,435 lb	12,389 lb	-17,610 lb	0.48	0.63	0.99
						11,084 lb/in	14,299 lb/in	25,451 lb/in	1.02	0.79	
7		20ft / 8ft	4:1	0.41	0.19	6,880 lb	5, 186 lb	-9,360 lb	0.25	0.34	1.94
						4,640 lb/in	5,985 lb/in	8,215 lb/in	0.33	0.26	
8		20ft / 8ft	2:1 & 4:1	0.51	0.26	9,466 lb	7,136 lb	-13,010 lb	0.35	0.47	1.73
						6,384 lb/in	8,236 lb/in	13,655 lb/in	0.55	0.42	

[A] PSW Predictions based on Configuration 1_{SPL}-C as a baseline (Baseline 1)
[B] PSW Predictions based on Configuration 9 as a baseline (Basline 2)
[C] Shaded cells indicate cases where the measured PSW Ratio (F) is below the calculated PSW Ratio (F)

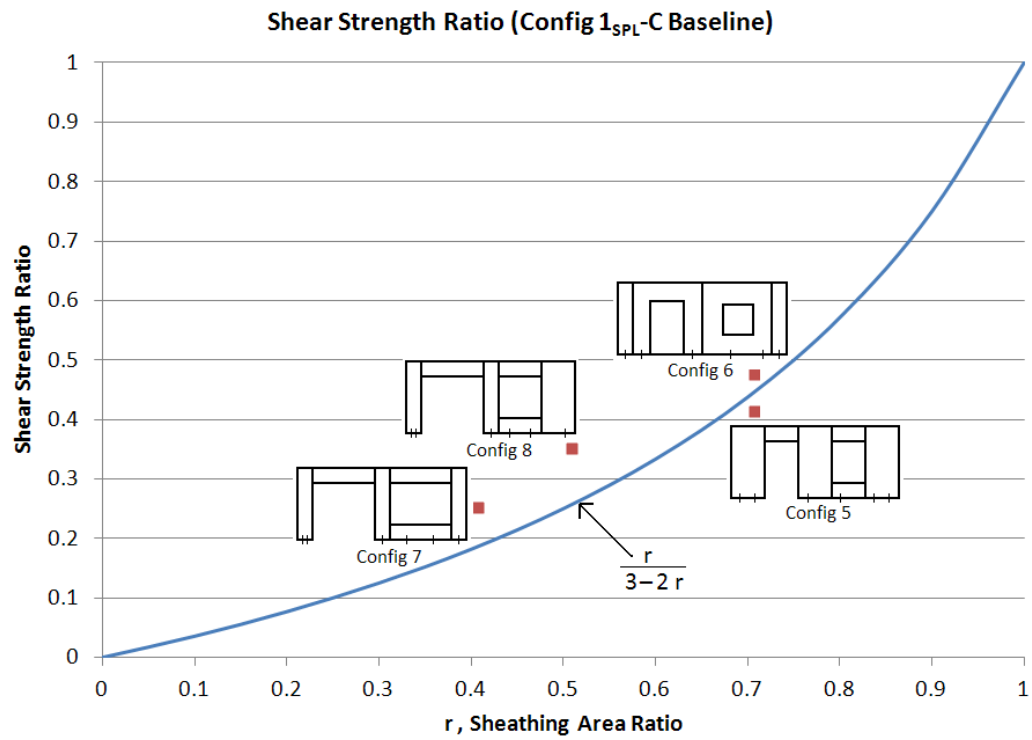


Figure 15. Shear Strength Ratio using Configuration 1_{SLP}-C as Baseline

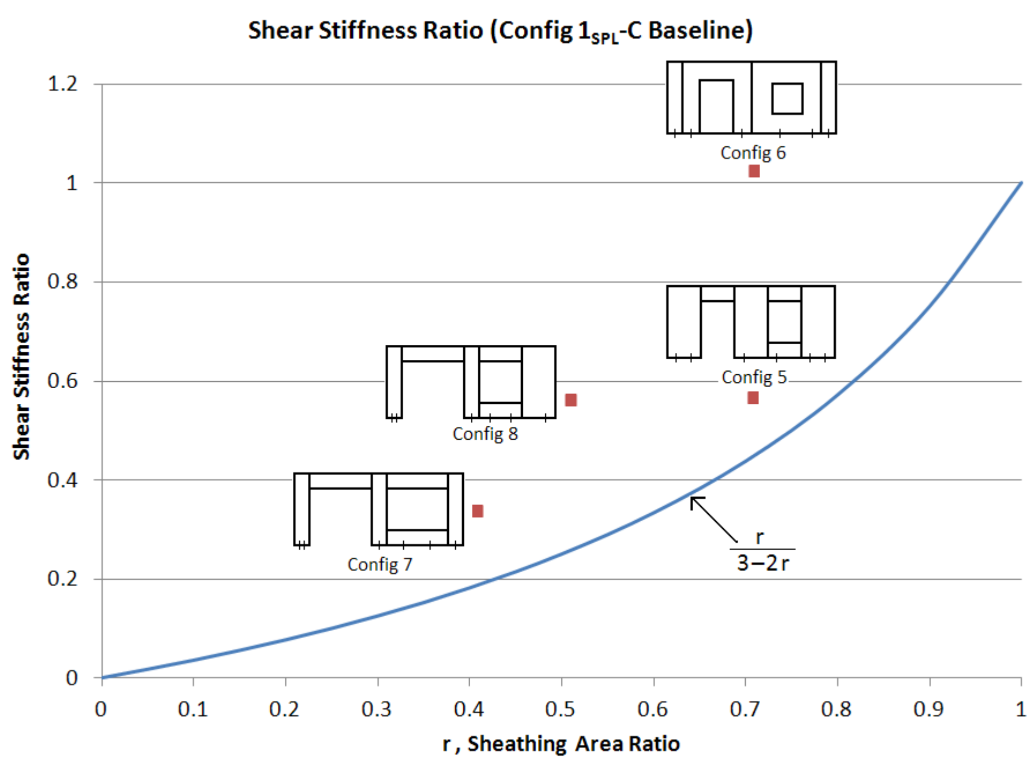


Figure 16. Shear Stiffness Ratio using Configuration 1_{SPL}-C as Baseline

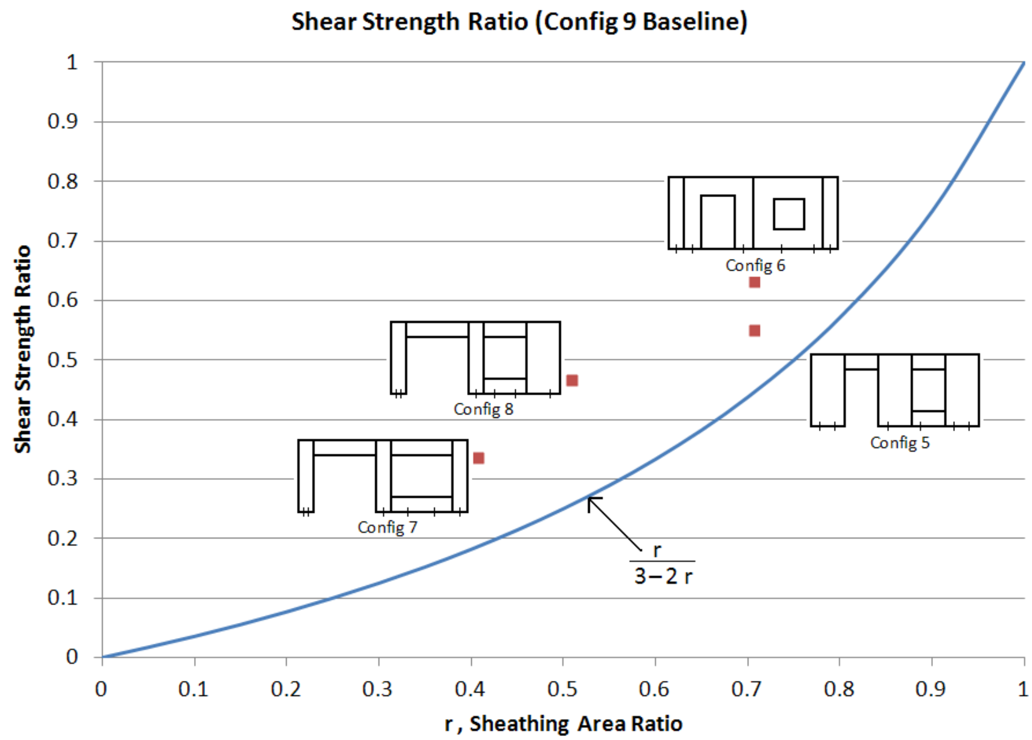


Figure 17. Shear Strength Ratio using Configuration 9 as Baseline

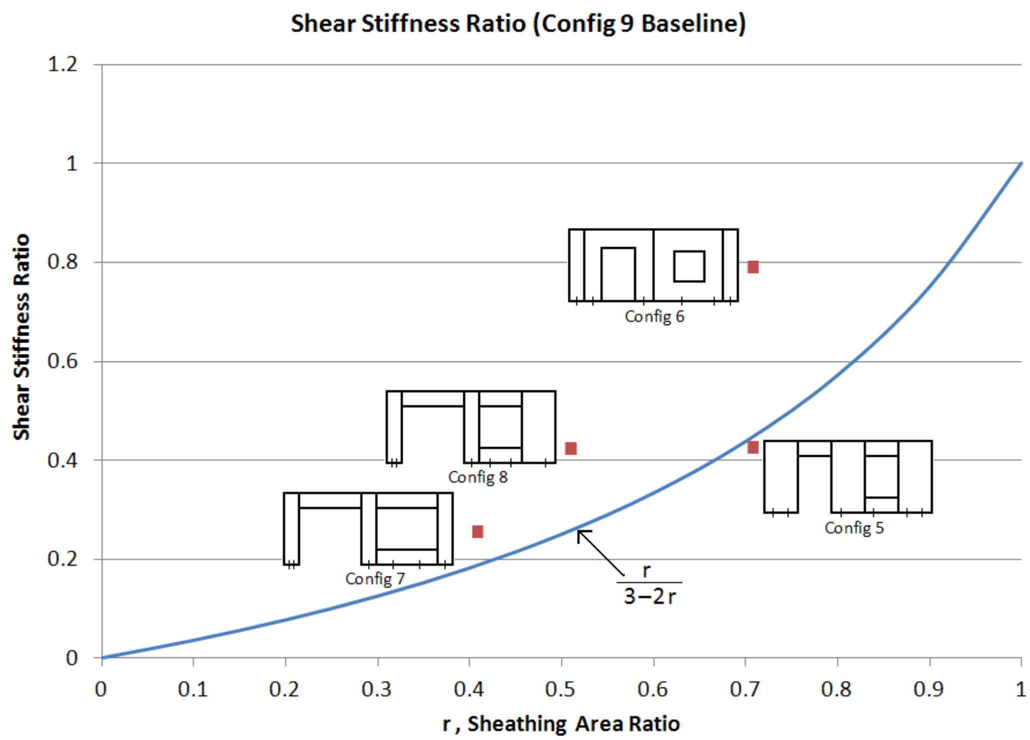


Figure 18. Shear Stiffness Ratio using Configuration 9 as Baseline

Figure 19. Configuration 5 Failure Mode at Header Panel

Summary and Observations

The results of this testing program provide information on the cyclic performance of SIP shear walls with various aspect ratios tested as individual wall segments or as part of a perforated shear wall line. The applicability of the PSW method to perforated SIP shear walls is also explored. Specific observations based on the test results include:

1. The measured unit shear capacity for fully-anchored SIP shear wall segments ranged from 1,400 lb/ft to over 2,100 lb/ft depending on the segment's aspect ratio.

2. The measured unit shear stiffness for fully-anchored SIP shear wall segments varied by a factor of two depending on the segment's aspect ratio.

3. The unit shear wall capacity and stiffness of SIP shear wall segments decreased with an increased number of panels jointed with a spline connection. A 25 percent decrease in unit shear was observed for a 20-foot wall with four spline joints compared to an 8-foot wall with one spline joint.

4. The unit shear wall capacity of SIP shear wall segments decreases with an increased segment's aspect ratio with a 16 percent decrease for a 2-foot segment as compared to a 4-foot segment.

5. The unit shear wall stiffness of SIP shear wall segments decreases with an increased segment's aspect ratio with a maximum 33 percent decrease for a 2-foot segment as compared to either an 8-foot or a 4-foot segment.

6. The test results indicate that perforated SIP shear walls closely follow the overall PSW method trend for both strength and stiffness.

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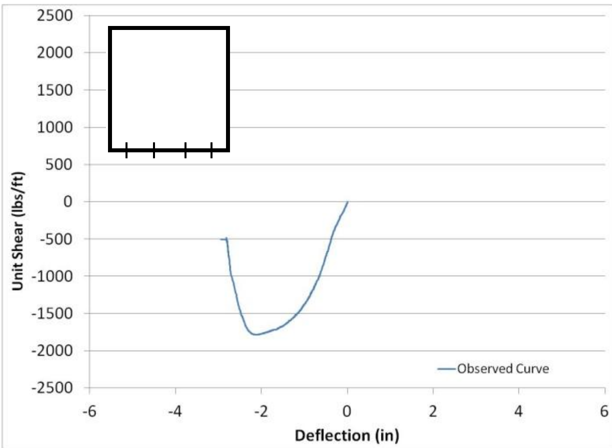
Appendix 1: Walls without Openings



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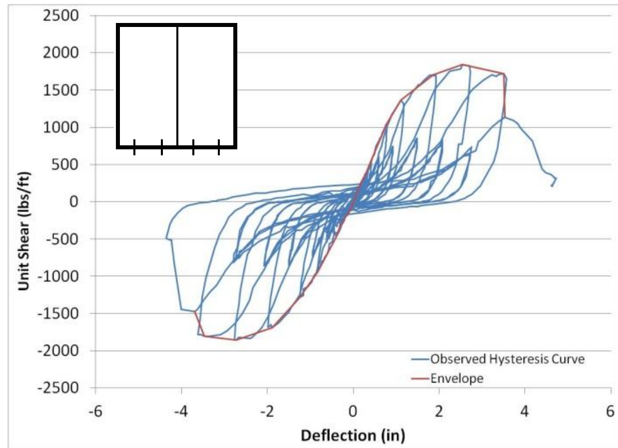
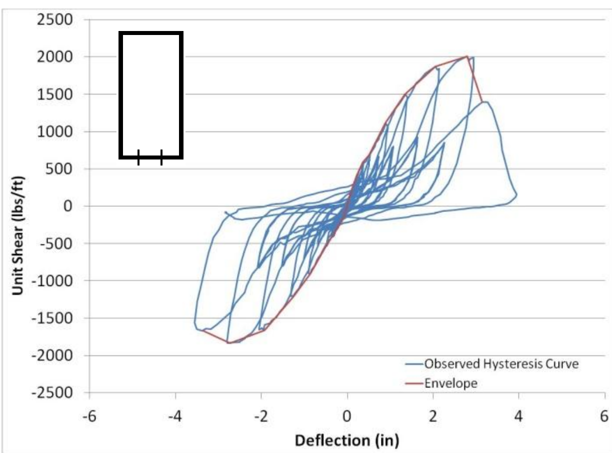


Configuration 1_{SPL}-C



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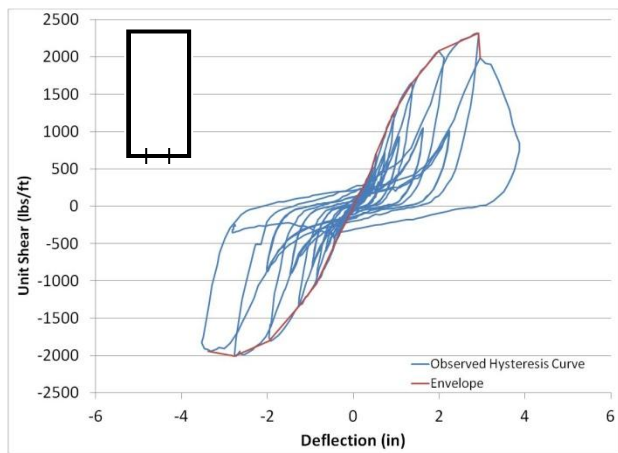

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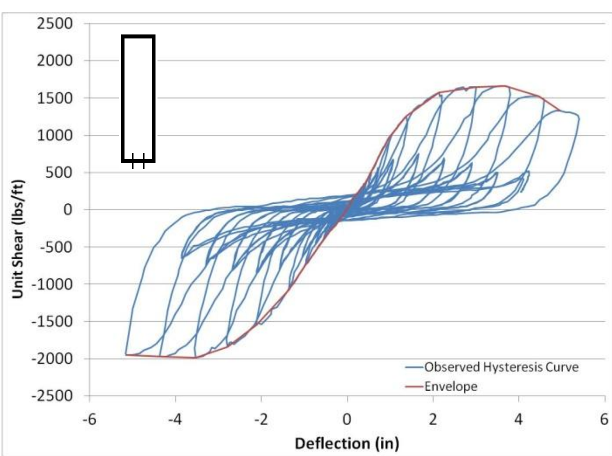

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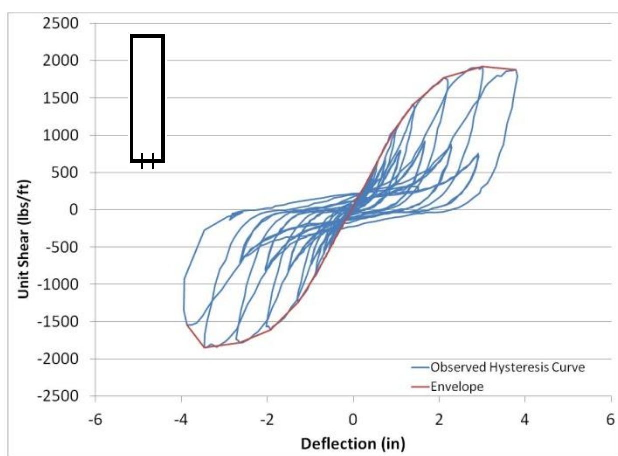

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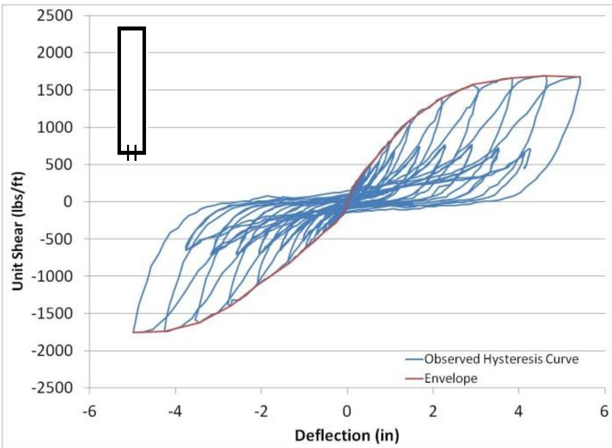

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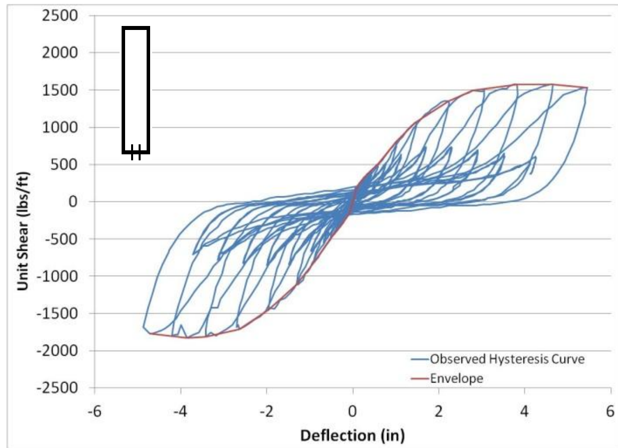

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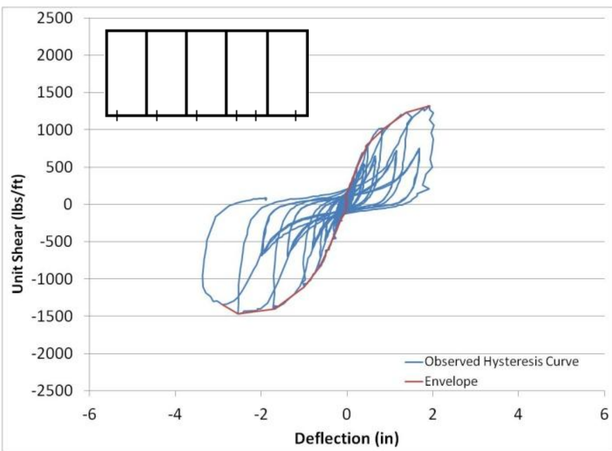
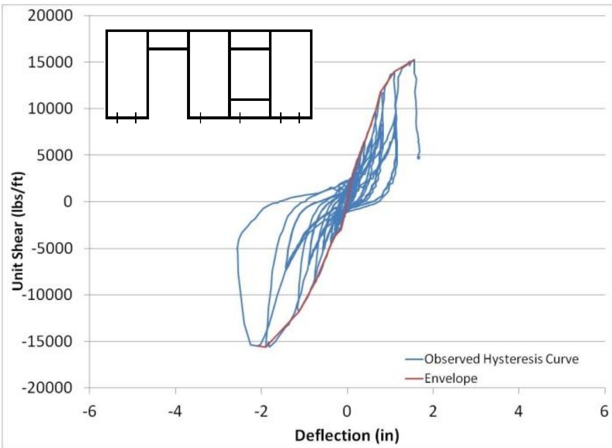


Configuration 9

Appendix 2: Walls with Openings



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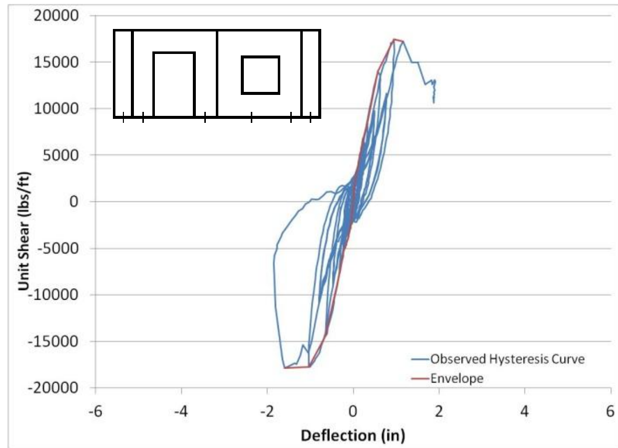

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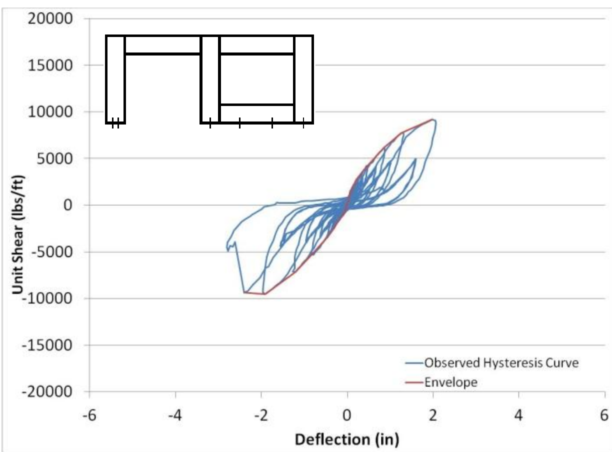

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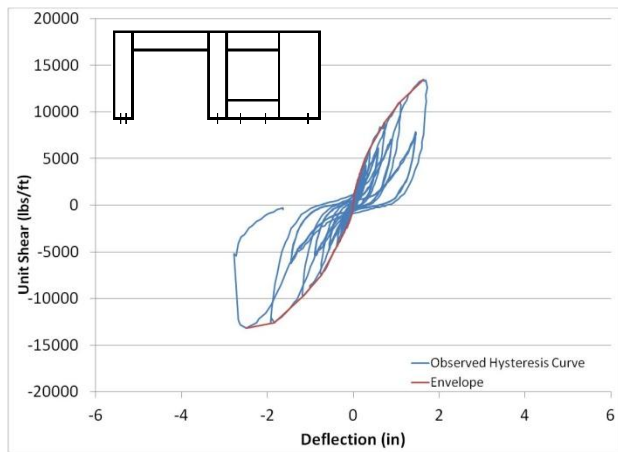

Configuration 8

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