Report No. WMEL 05-069

Cyclic Shear Wall Testing on Walls with Large Openings

Prepared
For

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By
Wood Materials and Engineering Laboratory
Washington State University
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1. Introduction

The Wood Materials and Engineering Laboratory (WMEL) at Washington State University in Pullman, WA, performed a series of cyclic shear wall tests using wood light-framing and incorporating specific details for fabrication and anchorage as recommended by the client. Two types of wall constructions were tested using two different hold-down methods for each wall type. All shear walls were tested according to ASTM E 2126-05 *Standard Test Methods for Cyclic (Reversed) Load Test for Shear Resistance of Walls for Buildings*. The specific procedure used was Method A (Section 8.3) which utilizes the Sequential Phase Displacement (SPD) Loading Protocol for the displacement pattern and frequency. This report includes descriptions of specimens and testing performed, and tabulated results of test data. Testing was conducted for comparison purposes with similar testing that was previously conducted at laboratories other than the WMEL.

2. Test Specimens and Specimen Preparation

2.1. Materials

Shear walls were fabricated using materials purchased from local suppliers and provided by the client. Lumber used for studs, end studs, top plates, bottom plates and headers was dry Douglas Fir No. 2 lumber. Headers utilized nominal 2 x 12 inch members, while all other framing consisted of nominal 2 x 4 inch members. Wall sheathing was 7/16 inch thick APA rated oriented strand board (OSB), and sheathing material used as spacers placed between the nominal 2 x 12's for the headers was 15/32-inch thick OSB. Typical ½ inch thick gypsum board was used to partially clad wall specimens on the sides opposite from the OSB sheathing. Segments of 5/8-inch diameter ASTM A-36 steel threaded rod were used with the wall hold-downs described below. Depending on the requirements, a combination of 0.131 x 2.5 inch (8d common) nails, 0.148 x 3.0 inch (10d common) nails, 0.162 x 3.5 inch(16d common) nails and 1-1/4-inch long Type W screws were used to fabricate the wall specimens. The materials above were procured from local suppliers by WMEL staff or faculty and were taken from suppliers' existing inventories. The client, Simpson Strong-Tie Company, Inc., provided Simpson PDH5 wall hold-down connectors (including adequate numbers of Simpson SDS1/4x3 wood screws), Simpson LSTA24 straps, segments of ½ inch diameter A-36 steel threaded rod with nuts, and 2 x 2 x 3/16-inch square flat plate washers. All of these products were manufactured by Strong-Tie Company, Inc. and were shipped directly to the WMEL.

2.2. Shear Wall Specimens

Fabrication details for the shear wall specimens tested were specified by the client. Both types of walls were 8-ft tall and 12-ft long and both had large openings in the center of the walls. Schematic drawings of the wall types tested are shown in Figures 1 and 2. The wall specimens were designated Wall 4_1 and Wall 6_1, based on the aspect ratios of the outermost vertical wall segments.

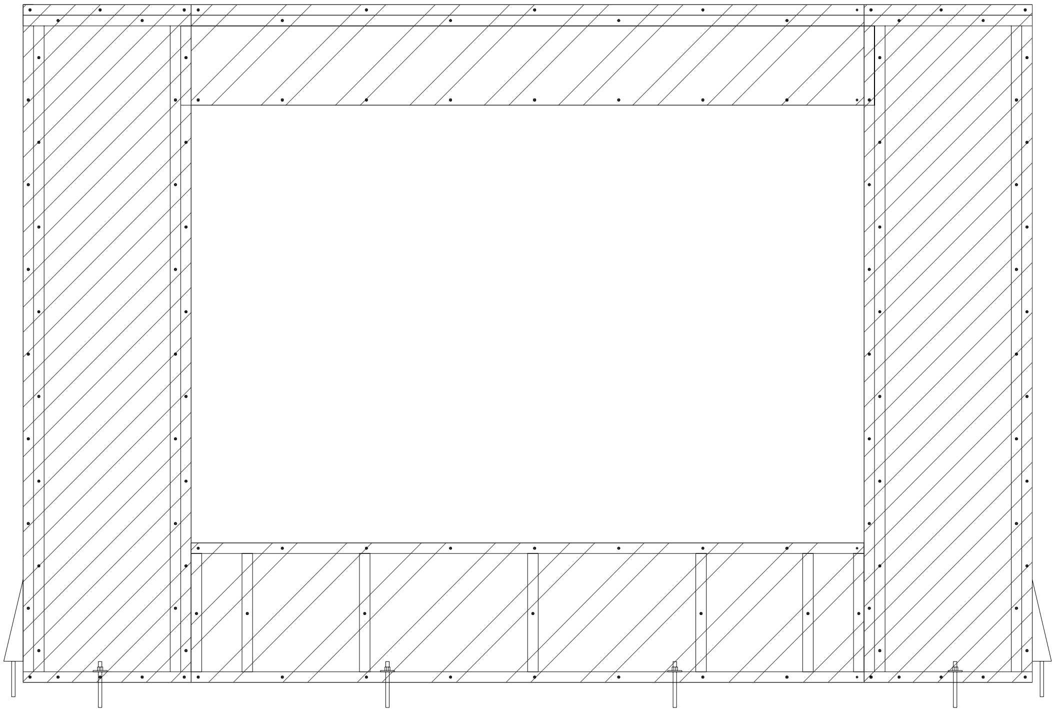

Figure 1. Diagram of Wall 4_1 Specimens Showing Framing, Anchorage, Hold-Downs, Sheathing and Sheathing Nails (Drawing Provided by Guy Anderson of Simpson Strong-Tie Company, Inc.)

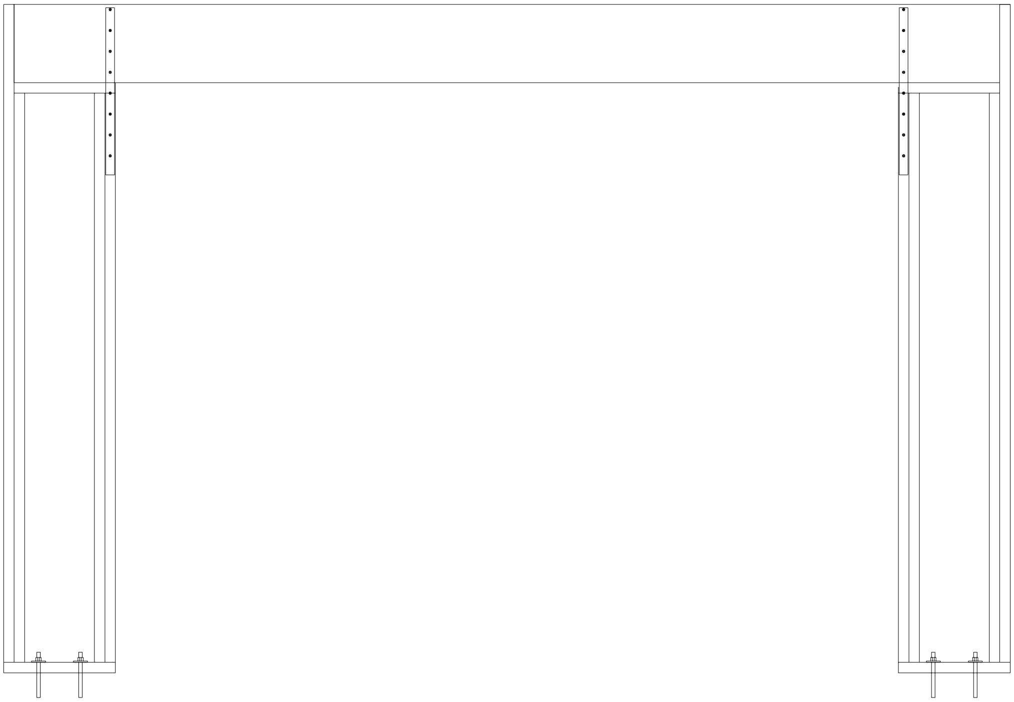

Figure 2. Diagram of Wall 6_1 Specimens Showing Framing, Anchorage, and Strapping Placed Between Framing and Gypsum (Drawing Provided by Guy Anderson of Simpson Strong-Tie Company, Inc.)

2.3. Shear Wall Fabrication

Wall 4_1 specimens were partially fabricated horizontally, lying flat on the laboratory floor, then lifted into position for the completion of fabrication and testing. The framing was assembled first by cutting all members to length and then nailing them together. Doubled studs were nailed together using 0.131 x 2.5 inch(10d common) nails at 24 inches on center (o. c.) and doubled top plates were nailed together using 0.162 x 3.5 inch(16d common) nails also at 24 inches o. c. after the lower top plate had been nailed to the tops of the studs. Top and bottom plates were nailed to studs using two 0.162 x 3.5 inch(16d common) nails into each stud. Headers consisted of a 15/32-inch thick OSB spacer sandwiched between two 2 x 12 members and were nailed together with 0.162 x 3.5 inch (16d common) nails at 16 inches o. c. along the top and bottom edges. Headers were installed by having four 0.162 x 3.5 inch (16d common) nails driven through studs and into the ends of the headers prior to installation of the top plates. Wall sheathing was cut to size and attached to one side of each wall using 0.131 x 2.5 inch (8d common) nails at 6 inches o. c. along all panel edges and 12 inches o. c. in the field of panels. Following installation of wall sheathing, 9/16-inch diameter holes were drilled in the bottom plates for anchor bolt installation, and wall specimens were placed into the testing apparatus and bolted to a steel tube that was rigidly attached to the laboratory reaction floor. The steel tube had holes drilled for the anchor bolts and hold-downs.

Wall 4_1 specimens were attached to the steel tube using four ½ inch diameter A-36 steel anchor bolts with large square plate washers placed beneath the nuts. Once the specimens were in place on the tube, ½ inch thick gypsum board was screwed to the side opposite from the wall sheathing using 1-1/4 inch long Type W screws at 12 inches o. c. around the edges and at 3 inches o. c. in the corner regions of the openings, as specified by the client. There was no gypsum board installed on top of the center 80 inches of the header for Wall 4_1 specimens. In the cases when hold-downs were used, they were installed on the outermost end stud by bolting the hold-down to the steel tube using 5/8 inch diameter A-36 steel threaded rod, and then screwing the hold-down to the stud using Simpson SDS1/4x3 wood screws in all available holes. The steel tube was fabricated such that the sheathing would not impinge on the beam as it was rotating during testing. This was accomplished by ensuring that the top 1 inch of the tube was only 3-1/2 inches wide, below which the beam was reinforced with steel plates in order to avoid any compression buckling of the tube walls during testing.

Wall 6_1 specimens were also partially fabricated horizontally, but in separate segments, which were placed in position for the completion of assembly and testing. The segments included 2 vertical framing assemblies and the headers, which were 141 inches in length. The framing members were cut to length and then nailed together. Doubled studs were nailed together using 0.148 x 3.0 inch (10d common) nails at 24 inches on center (o. c.) and bottom plates were nailed to studs using two 0.162 x 3.5 inch (16d common) nails into each stud. Headers consisted of a 15/32-inch thick OSB spacer sandwiched between two 2 x 12 members and were nailed together with 16d common nails at 16 inches o. c. along the top and bottom edges. Wall sheathing was cut to size and attached to one side of each segment using two rows of 0.131 x 2.5 inch (8d common) nails at 3 inches o. c. around the panel edges, except along the top and bottom of the segments, where only one row of nails was used. Following installation of wall sheathing, 9/16-inch diameter holes were drilled in the bottom plates for anchor bolt installation, and the vertical wall specimens were placed into the testing apparatus and bolted to the steel tube.

Wall 6_1 specimens were attached to the steel tube using four ½ inch diameter A-36 steel anchor bolts with large square plate washers placed beneath the nuts. Once the vertical segments were in place on the tube, headers were installed by having six 0.162 x 3.5 inch (16d common) nails driven through short horizontal plates and into the bottom of the headers where the headers rested on the vertical segments (see Figure 2). Additionally, where the wall sheathing overlapped the header (16 inches in from each end of the wall) the sheathing was nailed to the header using 0.131 x 2.5 inch (8d common) nails in a 3-inch o. c. grid. Following header installation, on the side of the wall to have the gypsum board installed, a Simpson LSTA24 strap was nailed to the header and vertical segment, as shown in Figure 2, on each side of the opening using 0.148 x 3.0 inch (10d common) nails. After the straps were nailed on, ½ inch thick gypsum board was screwed to the side opposite from the wall sheathing using 1-1/4-inch long Type W screws at 12 inches o. c. around the edges and at 3 inches o. c. near the ends of the gypsum, which only extended 32 inches in on each side from the edge of the walls, as specified by the client. There was no gypsum board installed on top of the center 80 inches of the header for Wall 6_1 specimens. In the cases when hold-downs were used, they were installed on the outermost end stud by bolting the hold-down to the steel tube using 5/8 inch diameter A-36 steel threaded rod, and then screwing the hold-down to the stud using Simpson SDS1/4x3 wood screws in all available holes.

For both types of specimens, all sheathing and framing nails were installed using a pneumatic nail gun and all nail spacings were measured and marked prior to driving the nails. The nail guns were set so that the nails would be flush or slightly proud of the plywood surface. Nails that remained above the surface of the OSB were driven flush by hand. All material utilized for fabrication of shear walls was stored at ambient laboratory conditions prior to and throughout testing.

Once specimens were fully assembled and fixed to the steel tube attached to the floor, a 3 inch wide steel tube was secured to the top plate or header of the walls using ½ inch diameter lag screws which were staggered at 12 inches o. c. along the length of the walls. This tube was connected to the hydraulic actuator used to induce displacement into the specimens with a connection that allowed rotation between the steel tube and the end of the actuator. Figure 3 shows a test specimen installed in the testing apparatus prior to initiation of the cyclic testing protocol.

Figure 3. Typical Wall 4_1 Specimen Being Installed in Testing Apparatus Prior to Testing.

3. Testing Methods

3.1. Introduction

Testing conducted on the shear wall specimens described above was in accordance with ASTM E 2126-05 *Standard Test Methods for Cyclic (Reversed) Load Test for Shear Resistance of Walls for Buildings*. The specific procedure used was Method A (Section 8.3) which utilizes the Sequential Phase Displacement (SPD) Loading Protocol for the displacement pattern and frequency. Testing was executed at the WMEL, which is accredited for testing in accordance with ASTM E 2126-05 by the International Accreditation Service as TL246. Provided in the following sections are descriptions of the tests conducted for Simpson Strong-Tie Company, Inc. on shear walls with large openings with and without hold-downs.

3.2. Testing Protocol

The shear wall testing was conducted in accordance with ASTM E 2126 utilizing the SPD, displacement controlled cyclic testing protocol. The steel tube that specimens were attached to and that was rigidly secured to the reaction floor of the laboratory was utilized to provide resistance to the applied test loads. As recommended by the client, the first major event (FME) used to scale the SPD displacement pattern was 1.2 inches. Section 8.3 of ASTM E 2126-05 provides guidelines for determining the displacement of the top of the wall based on the FME. Testing was conducted at a frequency of 0.2 Hz in order to avoid any inertia effects of the wall and the test fixtures. The maximum displacement of the specimens was 4.8 inches to either side of the starting position.

Once specimens were constructed and installed in the test fixtures, and the necessary data acquisition instrumentation installed and verified, loads were applied to the specimens by cycling the hydraulic actuator in positive and negative directions using the starting point as the point of reference. Lateral restraints (see Figure 3) were used at the top of the wall in two places and kept the top loading beam from moving more than ¼ inch to either side of the initial position. Hydraulic fluid pressure and actuator motion were controlled using an MTS Flextest SE Controller, which maintained the frequency throughout testing. All load and deflection data were continuously recorded at 0.1 sec. intervals throughout testing and were acquired using LabVIEW version 7.1 software. Four specimens were tested for each shear wall type, two using hold-downs and two without hold-downs. Following documentation of failure, specimens were unloaded, fixtures were removed and the specimens were disassembled for disposal and removed from the laboratory.

3.3. Specimen Instrumentation

In order to effectively acquire the data necessary to fulfill ASTM E 2126-05 requirements, one force transducer (load cell) and six string potentiometers were utilized to monitor the applied loads and displacements at several locations on each of the specimens. The force transducer had a capacity of 25,000 lb_f and was installed between the hydraulic actuator and the fixtures connected to the beam attached to the top of the wall and monitored loads resulting from the displacement protocol applied to the shear walls. One string potentiometer was used as a feedback transducer for the hydraulic actuator and was attached directly to the end of the actuator. Another string potentiometer recorded the movement of the top plate of the wall using a large steel column as the point of reference. Two string potentiometers were utilized on each end of the bottom of the wall to monitor vertical uplift and slip between the bottom plate and the steel tube.

All data acquisition instrumentation was calibrated by accredited calibration agencies according to the WMEL Quality Systems Manual guidelines for calibration frequency.

String potentiometers were also verified for accuracy using gauge blocks prior to each test conducted.

4. Testing Results

Results of the testing are presented in Table 1. Resistance force (load) was determined for each specimen at 0.24 inches and 0.48 inches as well as the ultimate values. The values were determined in two ways. First, an envelope curve was fit to the peak loads for each target displacement used for each phase in the testing protocol. This curve was then interpolated to determine the resistance (load) at the two displacements in each direction (i.e., positive and negative displacement). This data represents the average performance of specimens and removes errors due to the drift of interest falling in the valley of the data due to the pinching effects.

The second values were determined using the data directly. The recorded data trace was followed until the first time the displacement of interest was exceeded, and then the data was interpolated to determine the resistance (load) at the displacement of interest. Use of the actual data trace results in low resistance values due to the pinching effect.

All the analysis was completed on the data that was corrected for any recorded slip between the test fixture and the specimen. This removes the rigid-body deflections from the data, and results in only the racking behavior of the wall specimen being considered. The ultimate resistance (load) was determined directly from the data and is the maximum and minimum load recorded during the test.

Finally, the data from the positive and negative quadrants were averaged to provide an average resistance at each of the displacements of interest. These average value were then averaged for each configuration to provide a resistance (load) value for the configuration that can be used to compare to other test results. Individual specimen data has more variability and would be more difficult to gain meaningful information.

A comparison of the results of the 6:1 and 4:1 wall specimens is provided in Table 2 for each type of anchorage condition (i.e., with or without hold-downs). The comparisons are made with the slip corrected data values only. As can be seen in the data the 6:1 walls are significantly less stiff than the 4:1 walls (approximately 40% lower stiffness) and the ultimate of the 6:1 walls is 24% below that of the 4:1 walls for when hold-downs are not used and are 5% stronger with the hold-downs. However, a 5% difference is essentially equal for practical application of the results.

The individual test hystereses are included in the Appendix. The raw and corrected data is included on a compact disk, along with photographs of each of the failures.

Table 1(a). Results of Tests Based on Envelope Values (Values in lbs)

			Positive Envelope		Negative Envelope		Specimen Averages		Configuration Averages	
		Spec.	0.24 in	0.48 in	-0.24 in	-0.48 in	0.24 in	0.48 in	0.24 in	0.48 in
6:1 Walls	No Hold-Downs	6_1-1	494	773	-285	-462	390	618	438	692
		6_1-2	516	814	-457	-717	486	766		
	With Hold-Downs	6_1-3	682	1082	-547	-9980	615	1031	592	996
		6_1-4	488	818	-648	-1101	568	960		
4:1 Walls	No Hold-Downs	4_1-2	808	1205	-737	-1015	772	1110	738	1088
		4_1-4	665	984	-745	-1150	705	1067		
	With Hold-Downs	4_1-1	968	1507	-1088	-1605	1028	1556	990	1566
		4_1-3	748	1274	-1158	-1880	953	1577		

Table 1(b). Results of Tests Based on Slip Corrected Data (Values in lbs)

			Positive Envelope			Negative Envelope			Specimen Averages			Configuration Averages		
		Spec. No.	0.24 in	0.48 in	Ult.	-0.24 in	-0.48 in	Ult.	0.24 in	0.48 in	Ult.	0.24 in	0.48 in	Ult.
6:1 Walls	No HD	6_1-1	448	636	1494	-266	-457	-1492	357	547	1493	408	648	1665
		6_1-2	477	795	1872	-439	-701	-1802	458	748	1837			
	With HD	6_1-3	682	1024	3078	-540	-903	-3347	611	963	3212	588	924	3102
		6_1-4	499	730	2818	-629	-1042	-3163	564	886	2991			
4:1 Walls	No HD	4_1-2	494	948	2224	-716	-930	-2390	605	939	2307	636	947	2191
		4_1-4	662	921	1935	-670	-989	-2214	666	955	2075			
	With HD	4_1-1	786	1488	2808	-879	-1602	-2839	833	1545	2824	869	1493	2950
		4_1-3	740	1234	2811	-1070	-1648	-3338	905	1441	3075			

Table 2 Comparison of Results for Each Anchorage Condition Tested Using Slip Corrected Envelope Data (Ratios of 6:1 data /4:1 data)

	Displacement		
Anchorage Condition	**0.24 in**	**0.48 in**	**Ultimate**
No Hold-Down	0.59	0.64	0.76
With Hold-Down	0.60	0.64	1.05

Typical failure of the portal frame specimens are included in Figures 4 – 7. The typical failure was initial cracking of the gypsum panel at the top of the frame (Figure 4), followed by cracking of the OSB (Figure 5). Then at large displacements, the steel straps at the top of the wall would fail (Figure 6) and the hold-down post would split (Figure 7).

Figure 4. Typical Initial Failure of Portal Frame Specimens – Cracking of Gypsum Wallboard.

Figure 5. Secondary Failure of Portal Frame Specimens – Cracking of OSB.

Figure 6. Location of Third Failure in Portal Frame Specimens – Tension Failure of Straps.

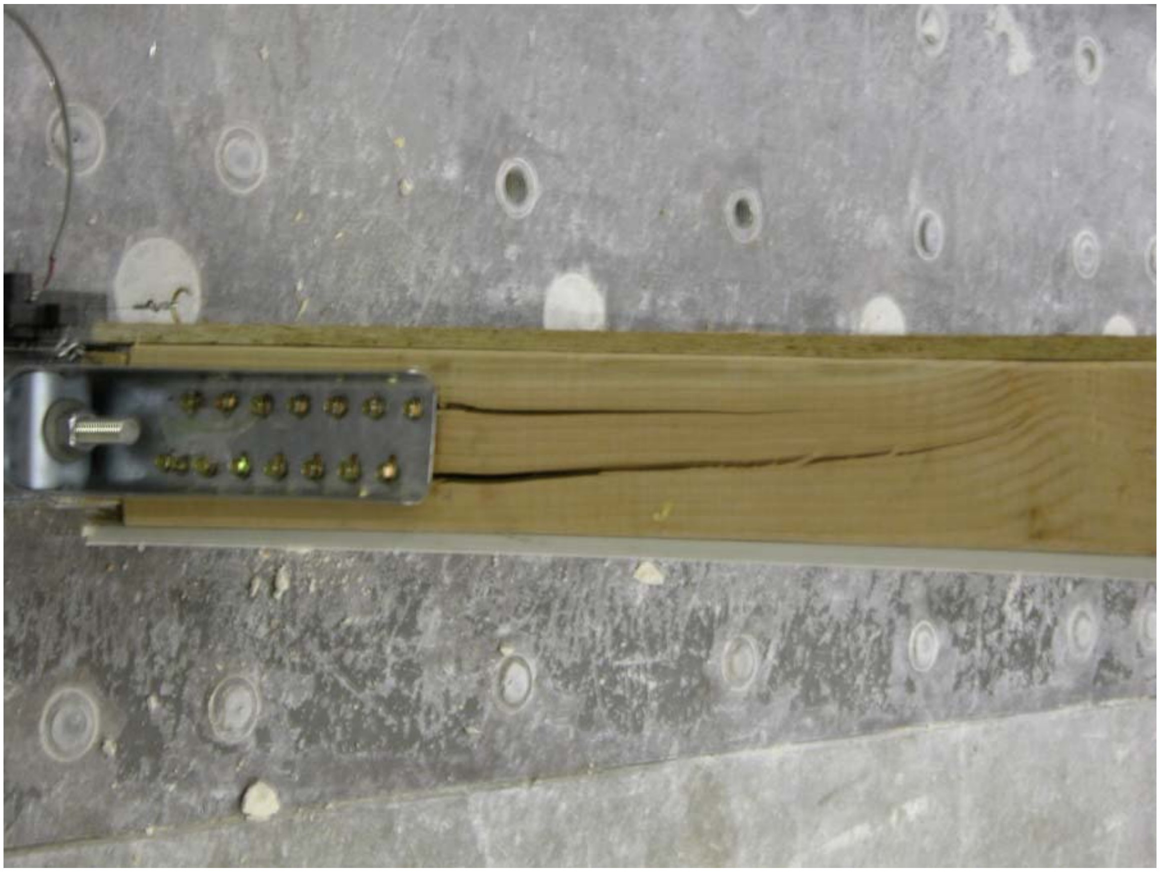

Figure 7. Typical Failure of Hold-Down Post – Occurred at Large Displacements.

Typical failure of the 4_1 Wall frame specimens are included in Figures 8 – 12. Failures were very similar to the portal frame specimens where the initial failure was due to cracking of the gypsum panel near the top of the frame (Figure 8), followed by tear-out of the nails securing the OSB (Figure 9). At larger displacements, there were no steel straps at the top of the wall to hold the segments together, which resulted in continued opening of the cracks in the gypsum and separation of the wall segments (Figures 10 and 11), until applied loads decreased and the hold-down post (where applicable) would split, or the wall segments would be lifted from the bottom plate (Figure 12).

Figure 8. Typical Initial Failure of 4_1 Wall Specimens – Cracking of Gypsum Wallboard (shown near top of specimen).

Figure 9. Secondary Failure of 4_1 Wall Frame Specimens – Separation and Cracking of OSB.

Figure 10. Continued Failure of 4_1 Wall Frame Specimens – Further Opening of Cracks in Gypsum.

Figure 11. Continued Failure of 4_1 Wall Frame Specimens – Separation of Wall Segments.

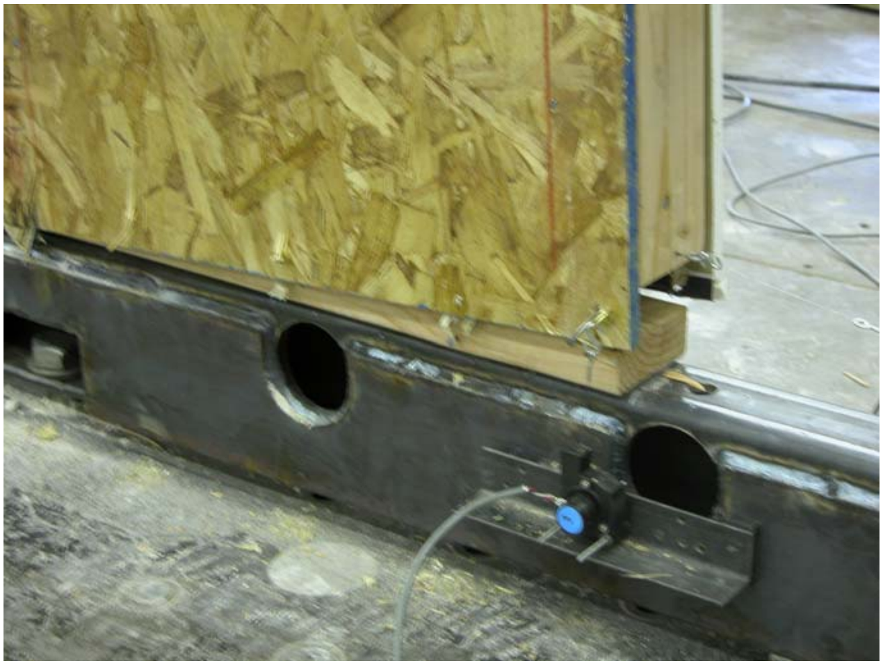

Figure 12. Lifting of Wall Segment from Bottom Plate on 4_1 Wall Specimens.

Testing was conducted by David M. Carradine, J. Daniel Dolan, Robert W. Duncan, Scott R. Lewis, and Steve Michael.

Report prepared by:

David M Carradine

David M. Carradine, Ph. D.
Technical Manager, and

J. Daniel Dolan, P. E., Ph. D.
Deputy Technical Manager

APPENDIX

This appendix is used to provide the hysteresis plots for the specimens tested. The plots are based upon the slip-corrected data.

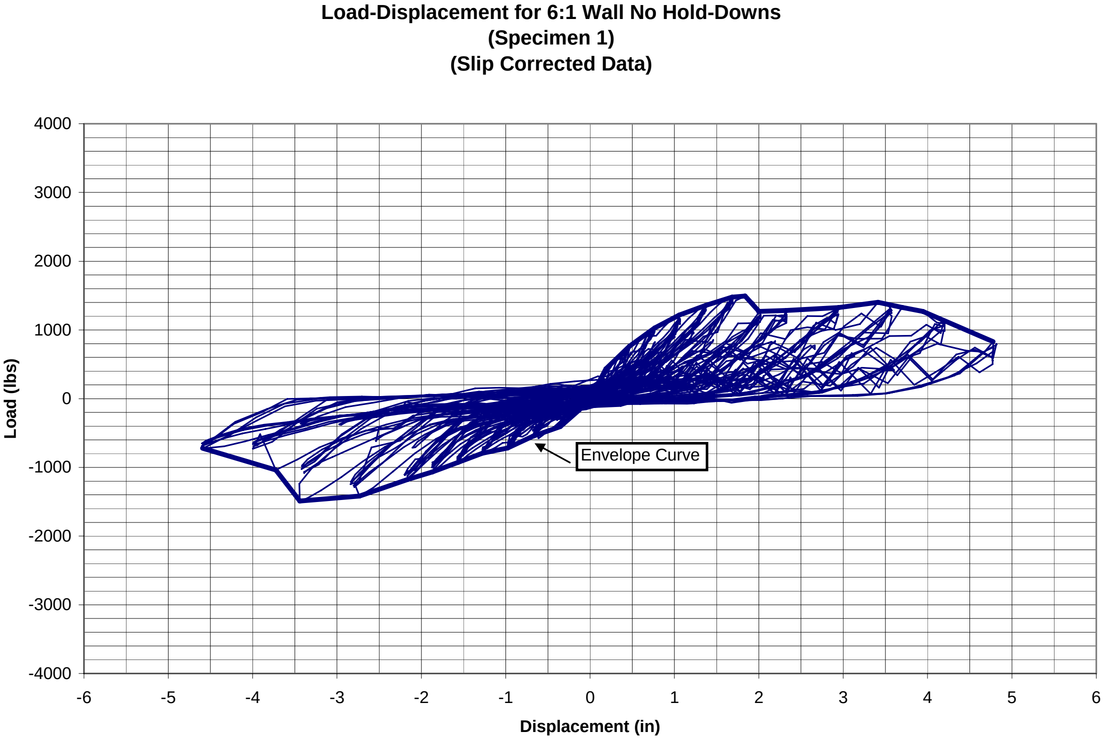

Figure A1. Hysteresis Plot for Specimen 6_1-1

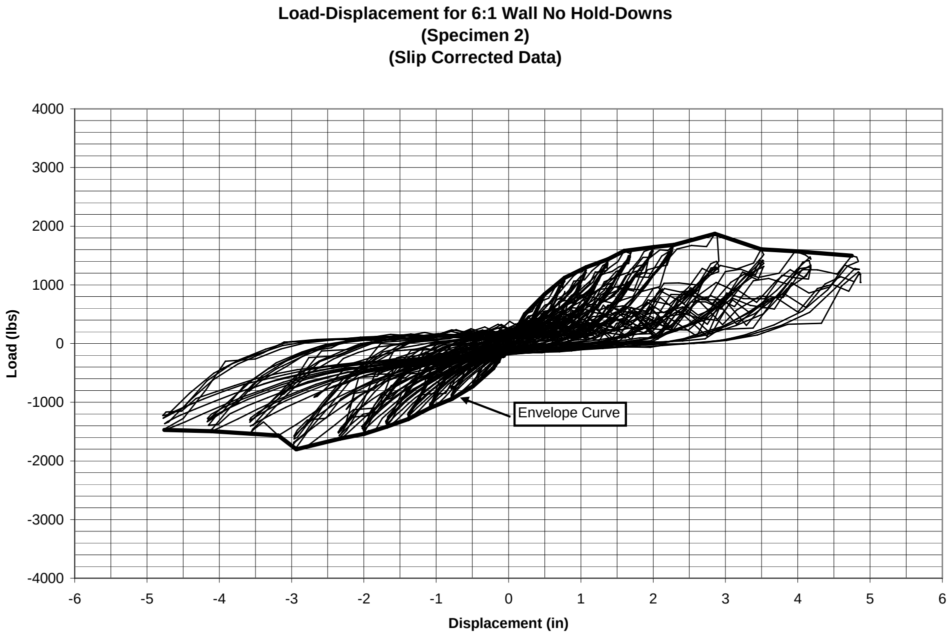

Figure A2. Hysteresis Plot for Specimen 6_1-2

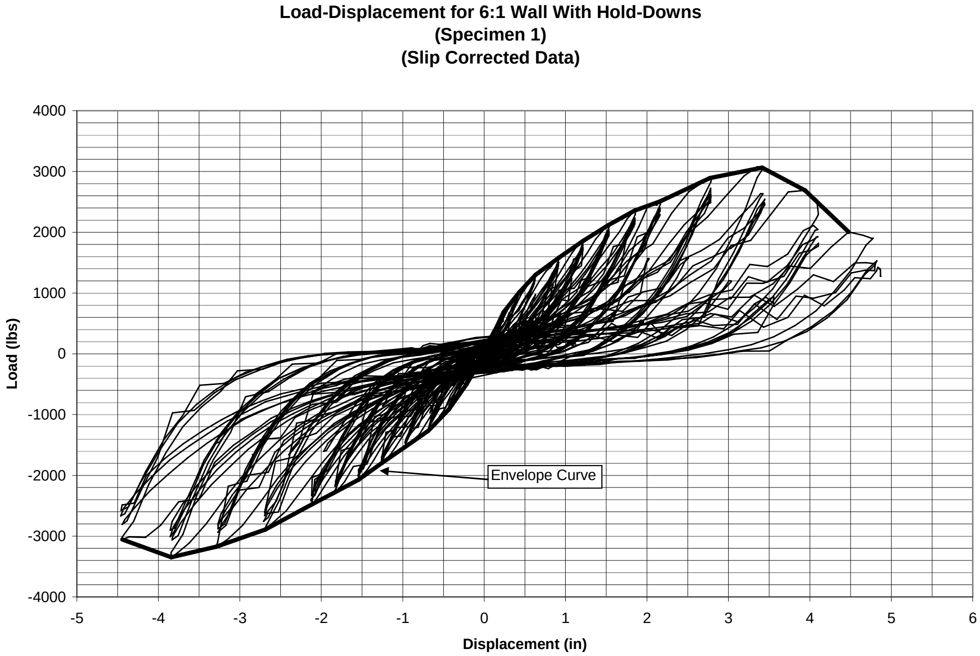

Figure A3. Hysteresis Plot for Specimen 6_1-3

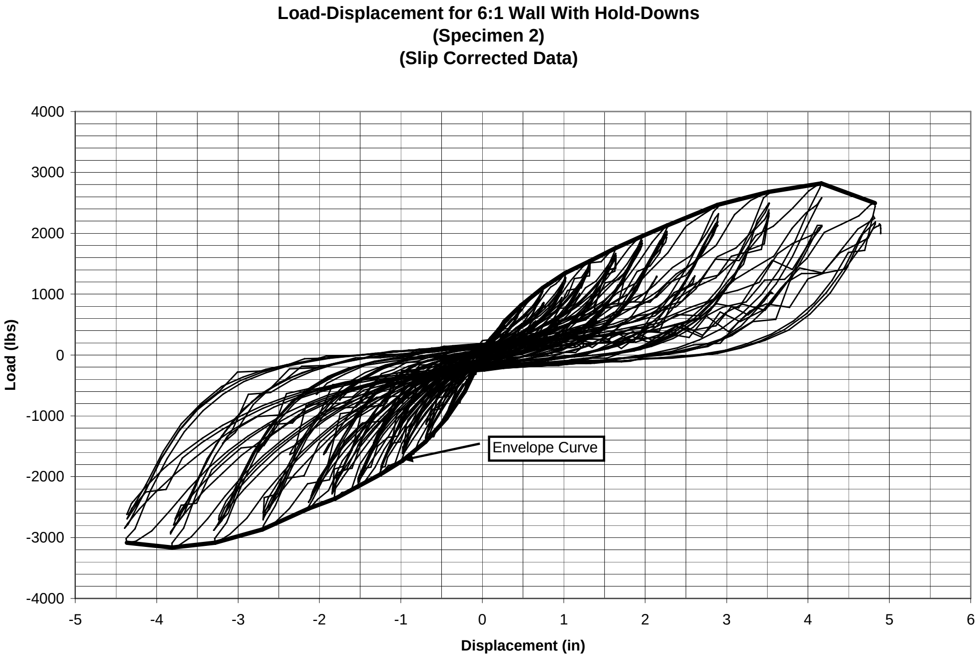

Figure A4. Hysteresis Plot for Specimen 6_1-4

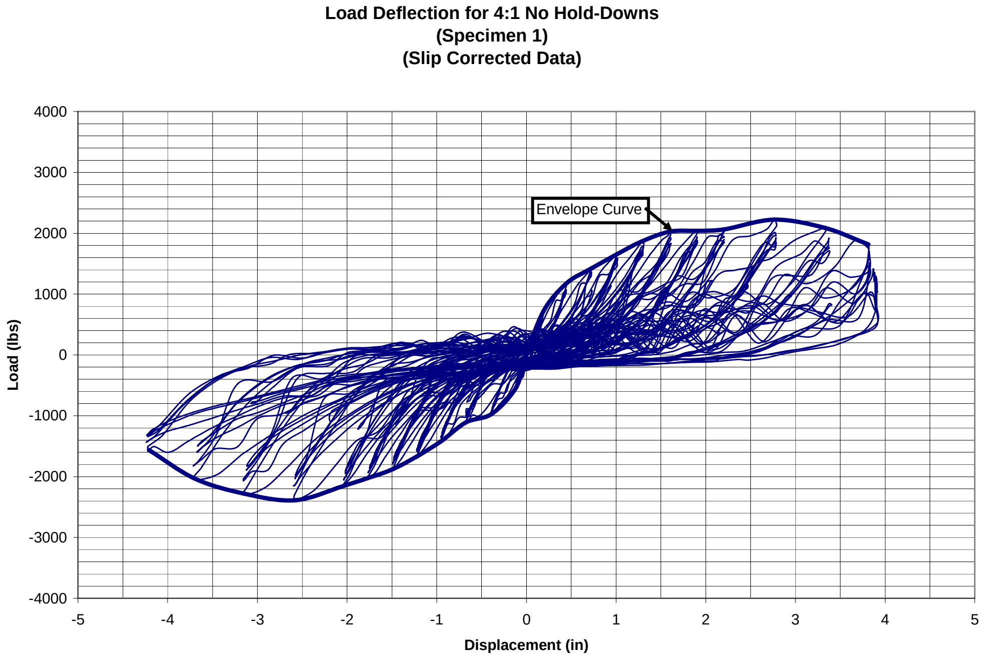
Load Deflection for 4:1 No Hold-Downs
(Specimen 1)
(Slip Corrected Data)

Figure A5. Hysteresis Plot for Specimen 4_1-2

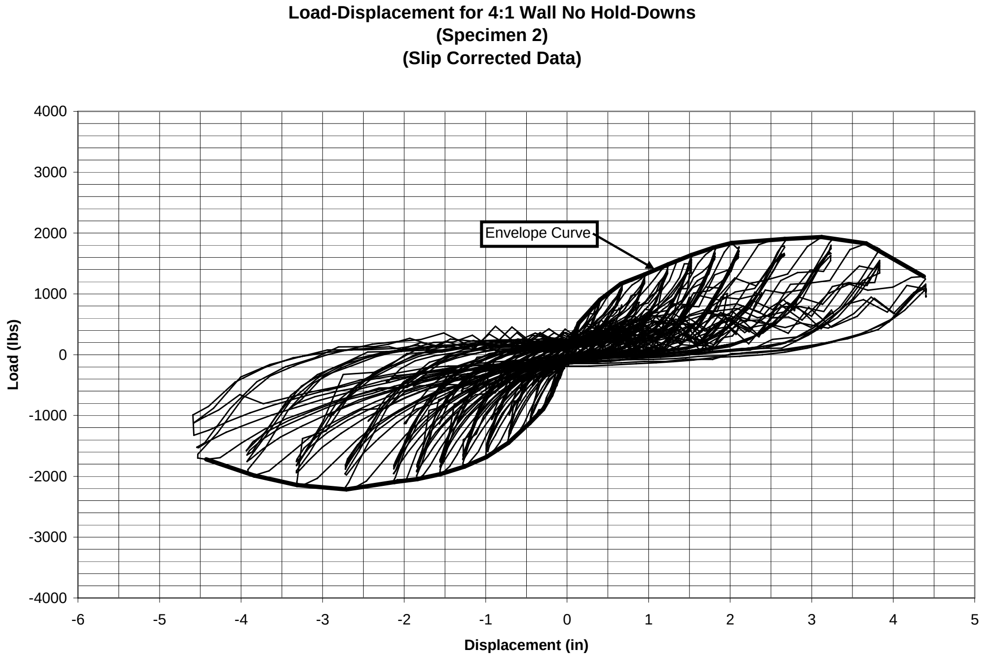
Load-Displacement for 4:1 Wall No Hold-Downs
(Specimen 2)
(Slip Corrected Data)

Figure A6. Hysteresis Plot for Specimen 4_1-4

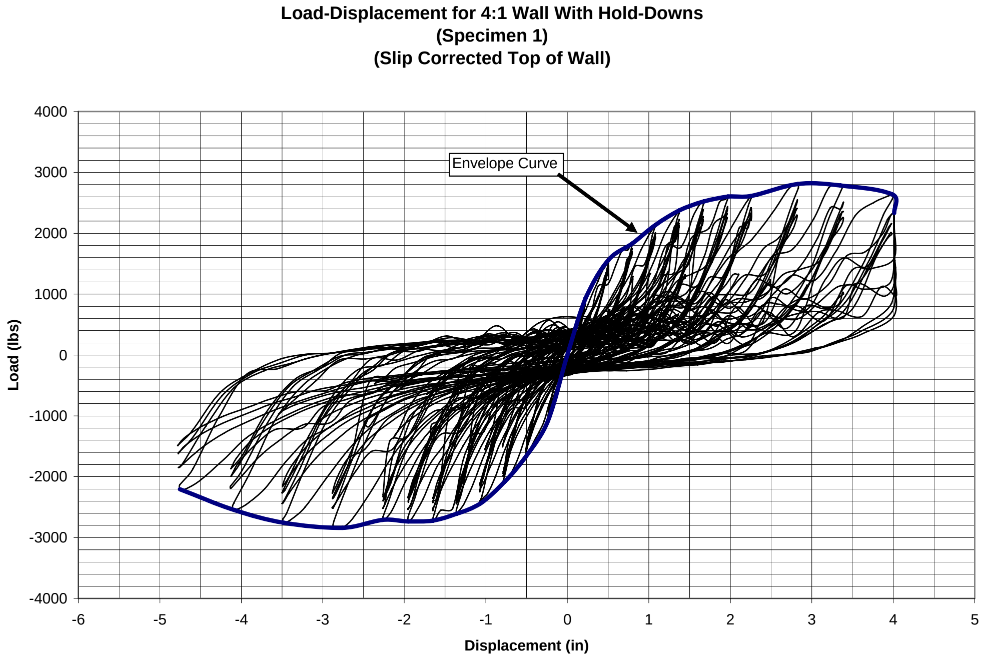

Figure A7. Hysteresis Plot for Specimen 4_1-1

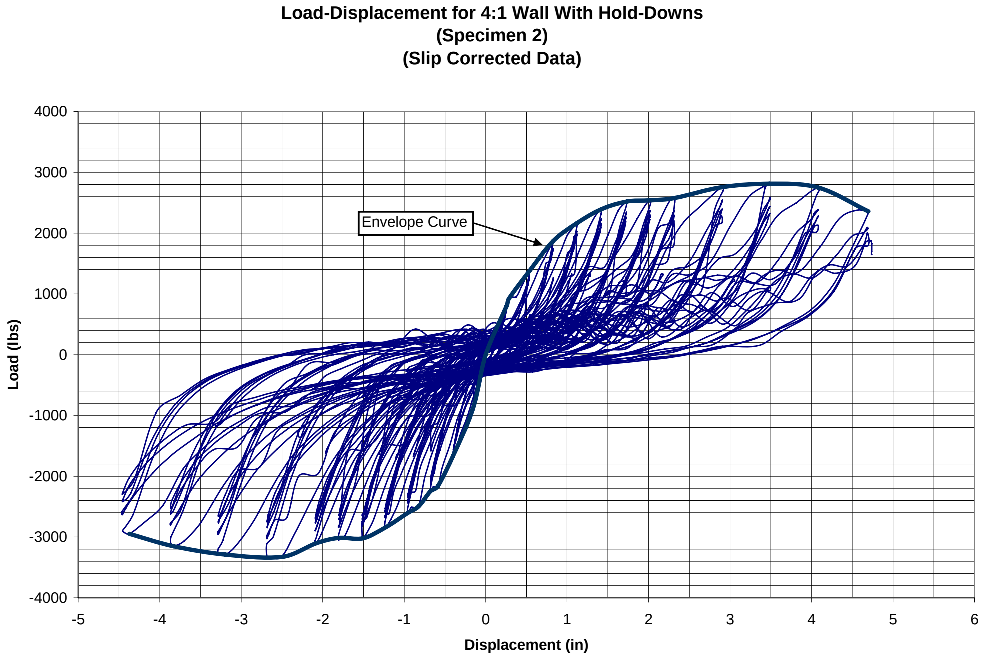

Figure A8. Hysteresis Plot for Specimen 4_1-3