APA

APA Report T2012L-30

Narrow Wall Bracing – Eight-Foot Tall Walls

by Edward L. Keith, P.E.
Technical Services Division
November 30, 2012

Accredited by
ACCREDITED TL-215

REPRESENTING THE ENGINEERED WOOD INDUSTRY
7011 South 19th Street • Tacoma, Washington 98466-5333 • Phone: (253) 565-6600 • Fax: (253) 565-7265 • www.apawood.org

Narrow Wall Bracing – Eight-Foot Tall Walls

SUMMARY

This report provides the results of full-scale tests conducted to determine the contribution of full-height braced wall elements in a continuously-sheathed wall line when those elements are less than the minimum required length in the 2012 International Residential Code (IRC) Table R602.10.5 - *Minimum Length of Braced Wall Panels*.

Testing was conducted on a pair of 12-foot long specimens, each with a single four-foot long, full-height wood structural panel (bracing panel) located in the middle of the specimen. These specimens formed the controls for the test program. Testing was conducted on eight-foot tall walls.

Additional specimens were fabricated and tested with the four-foot long, full-height bracing panel centered in the specimen as described above, but with additional narrow-length (24- and 20-inch long) full-height elements added in the wall line. Both door and window specimens were tested. The purpose of this testing was to compare the capacity of the control specimens with those having additional narrow-length elements. As both the control and test specimens contained a centrally located four-foot long, full-height bracing panel, the difference in capacity is used to determine the contribution of the narrow-length specimens when used in conjunction with full-length, full-height bracing panels.

Reported by:

EDWARD L. KEITH, P.E.
Senior Engineer
Technical Services Division

Reviewed by:

THOMAS D. SKAGGS, Ph.D., P.E.
Manager, Product Evaluation
Technical Services Division

Reviewed by:

BORJEN YEH, Ph.D., P.E.
Director
Technical Services Division

Accredited by

ACCREDITED TL-215

LABORATORY ACCREDITATIONS AND LISTINGS HELD BY APA

APA – The Engineered Wood Association is committed to providing its clients with high-quality service and information through documented test procedures and thorough, accurate collection of data. As a part of that commitment, a Quality Program has been established by APA based on the international document ISO/IEC Guide 17025: *General Requirements for the Competence of Testing and Calibration Laboratories*. The APA Quality Program follows the Accreditation Criteria and Requirements for Testing Organizations (CAN-P-4) and National Accreditation Program for Testing Organizations, Standards Council of Canada (SCC). APA is accredited or listed as a testing laboratory for specific scopes by the following agencies (certification agency accreditations also shown where applicable):

- International Accreditation Service (IAS), as an accredited Testing Laboratory (TL-215)
- International Accreditation Service (IAS), as an accredited Inspection Agency (AA-649)
- Standards Council of Canada (SCC), as an accredited Testing Organization (No. 89)
- Standards Council of Canada (SCC), as an accredited Certification Body
- Japanese Ministry of Agriculture, Forestry, and Fisheries (MAFF), as a Registered Overseas Certification Body (ROCB) since June 21, 2006
- The Florida Department of Business and Professional Regulation, as a Product Certification Agency (CER2512)
- The Florida Department of Business and Professional Regulation, as a Product Testing Laboratory (TST2513)
- The Florida Department of Business and Professional Regulation, as a Product Quality Assurance Entity (QUA2521)
- The Florida Department of Business and Professional Regulation, as a Product Validation Entity (VAL3120)
- City of Los Angeles, as a Compliance Assurance and Testing Agency (No. 22192)
- Miami-Dade County, as a Testing Laboratory (Certification No. 10-0817.11)

This report contains data generated through testing of engineered wood products according to various test methods. Many accepted test methods conducted by APA are accredited or listed by organizations listed above. A list of methods is available upon request. Any test data in this report that is derived from test methods, which deviate from accepted procedure are noted. Accreditation or listing does not constitute endorsement of this report by the accrediting or listing agency or government.

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

Table of Contents

1. INTRODUCTION

An area of concern with researchers and designers working with continuous-sheathed braced wall lines is the combination of full-height narrow-length (less than the minimum length required in the 2012 IRC Table R602.10.5) wall elements with full-length "qualified" braced wall elements. The problem lies in the understanding that the narrow-length elements are not as stiff as the full-length elements and would thus contribute less than could be expected by proportioning the capacity by length. The purpose of this research is to determine the magnitude of the reduced capacity that can be contributed by these narrow-length elements.

Similar research has been done for intermittent elements which led to the 2012 IRC Table R602.10.5.2 - *Partial Credit for Braced Wall Panels Less Than 48 Inches in Actual Length.* The difference in end-fixity of continuously-sheathed wall elements compared with intermittent elements makes the partial-credit table not applicable to continuously sheathed wall applications. In addition, APA Report T2012L-16, *Narrow Wall Bracing;* reported on the development of similar partial-credit tables for nine-foot tall walls. This current research project was designed to continue filling in the gap for continuously-sheathed wood structural panel wall bracing.

This report provides the results of full-scale tests conducted to determine the contribution of full-height braced wall elements in a continuously sheathed wall line when those elements are less than the minimum required length in the 2012 IRC Table R602.10.5 - *Minimum Length of Braced Wall Panels.*

Testing was conducted on a pair of 12-foot long specimens, each with a single four-foot long, full-height wood structural panel (bracing panel) located in the middle of the specimen. These specimens formed the controls for the test program. Testing was conducted on eight-foot-tall walls to supplement recommendations currently available for nine-foot walls. This height is common for second floor walls of multi-story residential structures.

Additional specimens were fabricated and tested with the four-foot long, full-height bracing panel centered in the specimen as described above, but with additional narrow-length (24- and 20-inch long) full-height elements added in the wall line. Both door and window specimens were tested. The purpose of this testing was to compare the capacity of the control specimens with those having additional narrow-length elements. As both the control and test specimens contained a centrally located four-foot long, full-height bracing panel, the difference in capacity was used to determine the contribution of the narrow-length specimens when used in conjunction with full-length, full-height bracing panels.

2. DEVELOPMENT OF THE MODEL

The methodology used was to first determine the capacity of a 48-inch long full-height section in a 12-foot long wall. As this is the CS-WSP methodology, it is reasonable and conservative to place the full-height section in the middle of the 12-foot wall and place a 16-inch deep sheathed element above each of the elements on the right and left side of the center-sheathed section. See Series C (Control) in Appendix A, Figure 2. This simulated a traditionally-sized man-door-height opening on either side of the full-height element. The assembly was tested to failure with the load at various deflections recorded electronically. The capacity of the specimen was analyzed in accordance with ICC-ES AC130. As such, the load (V_{LRFD}) at 0.60 inch

(0.025*H/C_d) was determined. From this load, the design capacity (V_{ASD}) and corresponding deflection was determined for the control.

The Control capacity determined the contribution of the 48-inch long element in any number of walls that contain a 48-inch long element plus narrow-length elements (see Figures 10 through 14 In Appendix A for wall-framing details).

3. MATERIALS AND METHODS

3.1 Test Frame

Testing was conducted on the cyclic load test frame at the APA Research Center in Tacoma, WA, as shown in Appendix A, Figure 1.

3.2 Wall Framing

Wall framing was 2x4 framing, 8 feet in height, SPF #2 or better. All plates were full length (12 feet or 11 feet-4 inches). The wall length was shortened to 11 feet-4 inches when testing 20-inch long panels. The shortening was necessary to maintain the geometry of the infill panel above the opening to 16 inches by 24 inches, as it was in the 24-inch long tests, eliminating one variable.

3.3 Wall Sheathing

Specimens were sheathed with 7/16 Performance Category, APA RATED SHEATHING, 24/16, Exposure 1, 4 feet x 8 feet. All panels were taken from the same production unit. Gypsum wall board was not added to the back side of the tested specimens.

3.4 Fastening

- Panels were fastened with 6d Common nails (2 inches x 0.113 inch in diameter) spaced at 6 inches on center around the panel perimeter and at 12 inches on center in the field of the panel.
- Double end-studs were stitched together with 10d Common nails (3 inches x 0.148 inch in diameter) spaced at 24 inches on center.
- Double top plates were stitched together with 10d Common nails (3 inches x 0.148 inch in diameter) spaced at 24 inches on center.
- Top and bottom plate to stud were end-nailed with (2) 16d Box nails (3-1/2 inches x 0.135 inch).

3.5 Anchor bolts

Each wall was attached to the test frame with two 5/8-inch anchor bolts placed within 6 to 12 inches from each end and one at or near the center of the wall. Standard cut washers were used and the anchor bolts were finger tight plus ¼ turn.

3.6 Hold downs

Each end of the specimens was tied down with an 800-lbf hold down, as required at the ends of a continuously sheathed braced wall line that does not meet the corner-return requirements of the 2012 IRC, Section R602.10.7. A Simpson anchor was attached to the inside of each double stud with three Simpson ¼ inch x 3 inches SDS screws to provide this hold-down-force capacity.

3.7 Test Specimens

The test specimens are discussed below and in Table 1.

Table 1. Test Specimens

Test Series	Test Name	Test Number	Description
C	Control	C-1	12′ wall with 48″ WSP braced wall panel centered
		C-2	
1A	24″ element with man-doors	1A-1	12′ wall with 48″ WSP braced wall panel centered + 24″ man-doors
		1A-2	
2A	24″ element with 60” tall windows	2A-1	12′ wall with 48″ WSP braced wall panel centered + 24″ windows
		2A-2	
1B	20″ element with man-doors	1B-1	11′-4″ wall with 48″ WSP braced wall panel centered + 20″ man-doors
		1B-2	
2B	20″ element with 60” tall windows	2B-1	11′-4″ wall with 48″ WSP braced wall panel centered + 20″ windows
		2B-2	

CONTROL SERIES C: Control Series C, as shown in Appendix A, Figures 2, 3, and 10, contained a 48-inch, full-height, wood structural panel braced wall panel centered within a 12-foot long wall specimen. As the Controls were fabricated to model continuously-sheathed wall elements, both sides of the center braced wall panel were framed (see Appendix A, Figure 10) and sheathed as for a 48-inch wide x 80-inch tall man-door. This wall was tested to failure with the load at various deflections recorded electronically. The load (V_{ASD}) was derived from V_{LRFD} determined at 0.60-inch deflection. As these walls contained just a 48-inch long element centered in the length of the wall, and the other tested walls contained the same element in addition to the narrow-length wall panels, the capacity of Controls formed the basis by which the narrow-length walls were compared.

SERIES 1A: Series 1A, as shown in Appendix A, Figures 4, 5, and 11 contained the 48-inch long element as well as two 24-inch long elements. This wall was tested to failure with the load at various deflections recorded electronically. The load (V_{ASD}) was derived from V_{LRFD} determined at 0.60-inch deflection. As this wall contained a 48-inch long element as well as two 24-inch long elements, the contribution of the two 24-inch long elements was determined by subtracting the Control capacity. The remainder (the contribution of the two 24-inch long elements) was compared with the Control (which represents a full 48-inch long element) and a reduction factor for the 24-inch long elements was determined with the following equation. (Note that the equation is greatly simplified by the fact that the narrow-length elements equal 48 inches as does the Control.)

$$R_A = (P_A - P_c) / P_c \qquad \text{Equation 1}$$

Where:
R_A = reduction factor for Series A walls
P_A = Load (V_{ASD}) of Series A wall (lbf)
P_c = Load (V_{ASD}) of Control wall (lbf)

SERIES 2A: While the above R factor is appropriate for a wall with man-doors, it is assumed that an actual wall will have more windows than doors and that a wall with windows would have a different R factor. It is further assumed that these windows would be no greater than 5 feet in height. Series 2A reproduced the Series 1A testing but with continuously-sheathed wall elements at the bottom of the openings to simulate 5-foot window openings (see Appendix A, Figures 6, 7, and 12).

As in the Series 1A tests, the load (V_{ASD}) was derived from V_{LRFD} determined at 0.60-inch deflection. The assembly was used as above and Equation 1 was used to compute the R factor for the Series 1B wall.

Series 1B & 2B: This second series of walls duplicate the above but with 20-inch long elements. See Appendix A, Figures 5, 8, and 13 and Appendix A, Figures 7, 9, and 14 for Series 1B and 2B, respectively. The same Control assembly was used but the use of 20-inch long elements required slightly different framing (see Appendix A, Figures 13 and 14 for Series 1B and 2B, respectively) to accommodate the shorter wall elements. Note that the wall length was reduced to 11 feet-4 inches in order to maintain the same framing and geometry of the rectangular elements above and below the openings as was used in the Series 1A and 2A tests. This was done to maintain similar end-fixity (both top and bottom of wall height segment) for both narrow wall lengths.

The use of 20-inch wall elements in conjunction with 48-inch wall elements necessitated the use of a more generic equation to calculate the R factor.

$$R_B = ((P_B - P_c)/40) / (P_c/48)) \qquad \text{Equation 2}$$

Where: R_B = reduction factor for Series B walls
P_B = Load (V_{ASD}) of Series B wall (lbf)
P_c = Load(V_{ASD}) of Control wall (lbf)

3.8 Instrumentation

Instrumentation was provided as shown in Appendix A, Figure 15. Linear potentiometer devices were attached to the test specimen and test frame or instrument stands with bolts, nuts and washers. The applied load was measured with a load cell located between the MTS hydraulic actuator and the load head.

3.9 Test Methods

The CUREe cyclic load protocol was used (ASTM E2126). Displacement was applied to the wall at a rate of 0.5 Hz and data recorded at 500 Hz. The data was averaged so that 100 data points per cycle were reported.

The load head used along the top of each wall specimen had an EI that was lower than the maximum required by ASTM E2126.

4. RESULTS AND DISCUSSION

Test results of this study are shown in Tables 2 and 3. ASTM E2126 plots for the below tests can be found in Appendix B.

Table 2. Test Results - Narrow Wall Bracing - ASD - Method AC130

Test Number	ASD Method AC130			Average			R^c ASD Method AC130
	Load at 0.6" (V_{LRFD}[a]) (lbf)	V_{LRFD}/1.4 Load (V_{ASD}) (lbf)	Defl. at V_{ASD}[b] (in.)	Load at 0.6" (V_{LRFD}[a]) (lbf)	V_{LRFD}/1.4 Load (V_{ASD}) (lbf)	Defl. at V_{ASD}[b] (in.)	
C-1	1259	899	0.369	1267	905	0.381	--
C-2	1275	911	0.392				
1A-1	2092	1494	0.329	2006	1433	0.313	0.58
1A-2	1920	1371	0.296				
2A-1	2917	2083	0.291	2747	1962	0.292	1.17
2A-2	2576	1840	0.293				
1B-1	2022	1444	0.340	2021	1443	0.320	0.71
1B-2	2020	1443	0.299				
2B-1	2454	1753	0.273	2430	1735	0.285	1.10
2B-2	2403	1716	0.296				

[a] V_{LRFD} = shear force at a deflection of 0.025 x H / C_d = 0.6 for an H of 96" and a C_d = 4 (Table 12.2-1, ASCE 7-10). Average of plus and minus values.
[b] $V_{ASD} = V_{LRFD} / 1.4$.
[c] The "R" factor used in this report is as described in the report and is not to be confused with the seismic response modification coefficient ("*R*") used elsewhere. See Section 3.7 of this report for "R" factor calculation.

Table 3. Test Results – Narrow Wall Bracing – Strength-Based ASD - Method AC130

Test Number	Specimen Average[a]		Series Average[a]			Ratio of (test series value/ control value)	
	Deflection at Ultimate (in.)	Ultimate Load (lbf)	Deflection at Ultimate (in.)	Ultimate Load (lbf)	Ultimate Load/2.5 (lbf)	Deflection at Ultimate	Ultimate Load
C-1	2.050	2215	2.094	2207	883	1.00	1.00
C-2	2.137	2199					
1A-1	1.927	3307	1.908	3098	1239	0.91	1.40
1A-2	1.889	2898					
2A-1	1.853	4305	1.998	4054	1626	0.96	1.84
2A-2	2.142	3803					
1B-1	1.538	2821	1.885	2967	1187	0.90	1.35
1B-2	2.232	3113					
2B-1	2.119	3766	2.363	3801	1521	1.13	1.72
2B-2	2.608	3837					

[a] Average provided is average of plus and minus values.

5. CONCLUSION

Based on the AC130 ASD design methodology, it can be seen from Table 2 that the use of a 24-inch long full-height panel section in a continuously sheathed eight-foot tall wall contributes from 58 percent (0.58 X 24 = 14 inches) to 117 percent, rounded down to 100 percent (1.00 x 24 = 24 inches) for elements adjacent to an 80-inch man-door and 60-inch window, respectively. In a similar manner, use of a 20-inch long full-height panel section in a continuously sheathed eight-foot tall wall contributes from 71 percent (0.71 X 20 = 14 inches) to 110 percent, rounded down to 100 percent (1.00 x 20 = 20 inches) for elements adjacent to an 80-inch man-door and 60-inch window, respectively. This can be seen in Table 4.

Table 4 was developed based on the R factors determined in Table 2, which were based on AC130 ASD deflection design methodology.

Table 4. Partial Credit for CS-WSP less than full length – 8-foot walls[a]

Bracing Method	Wall Height (ft)	Length of full height Method CS-WSP panel (in.)	Adjacent to a clear opening height (in.) or less	Contributing length of braced wall panel (in.)
CS-WSP	8	24	≤60	24
			64	22
			68	20
			72	18
			76	16
			80	14
		20	≤60	20
			64	19
			68	18
			72	16
			76	15
			80	14

[a] Linear interpolation shall be permitted

Table 3 contains the results of the AC130 Strength-Based (Ultimate/2.5) design methodology. It can be seen that the continuously-sheathed walls performed effectively equal to or, in most cases, better than the Controls by a significant margin in both design strength and stiffness, regardless of the opening size.

6. REFERENCES

APA – The Engineered Wood Association. 2012. APA Report T2012L-16. *Narrow Wall Bracing*. Tacoma, WA.

ASCE. 2010. Minimum Design Loads for Buildings and Other Structures, ASCE/SEI 7-10. Reston, VA.

ASTM International. 2011. *Standard Test Methods for Cyclic (Reversed) Load Test for Shear Resistance of Vertical Elements of the Lateral Force Resisting Systems for Buildings,* ASTM E2126-11. West Conshohocken, PA.

ICC-ES. 2009. *Acceptance Criteria for Prefabricated Wood Shear Panels,* AC-130. International Code Council Evaluation Service, Inc. Whittier, CA.

IRC. 2012. *International Residential Building Code*. International Code Council. Country Club Hills, IL.

7. APPENDICES

List of Appendices

Appendix A: Figures (15 pages)

Figure 1. Test Frame with Test Wall in Place.

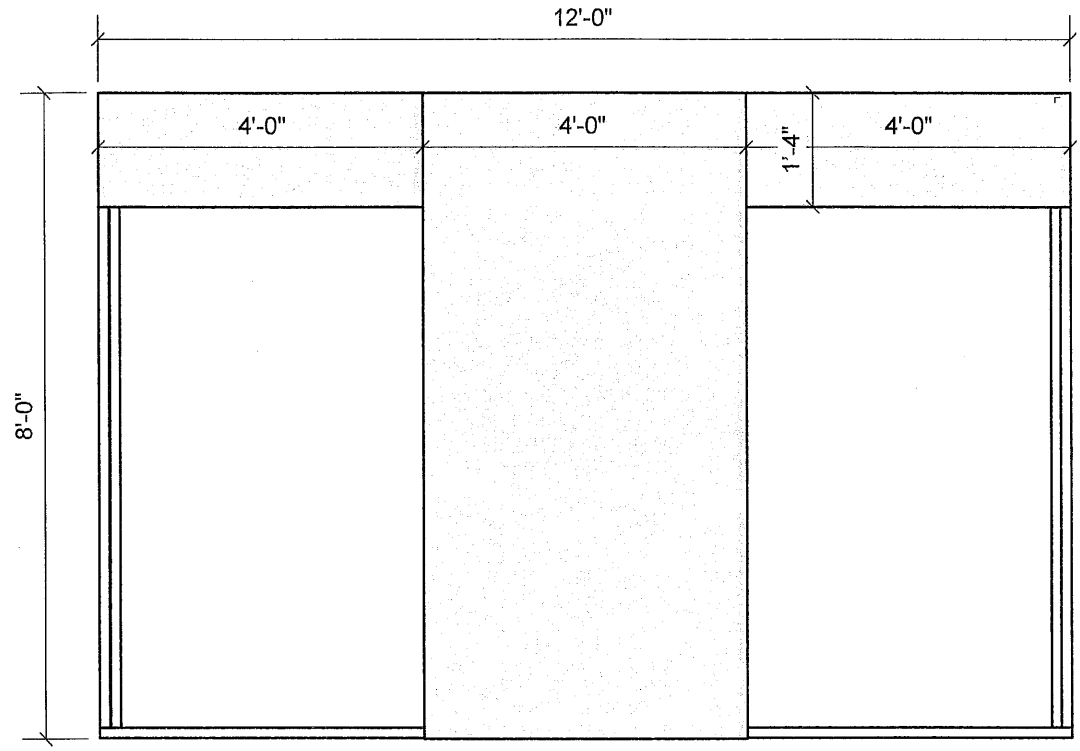


Figure 2. Control: Panel Placement.

Figure 3. Cyclic Load Test Machine with Test C-1 (Control) Wall in Place.

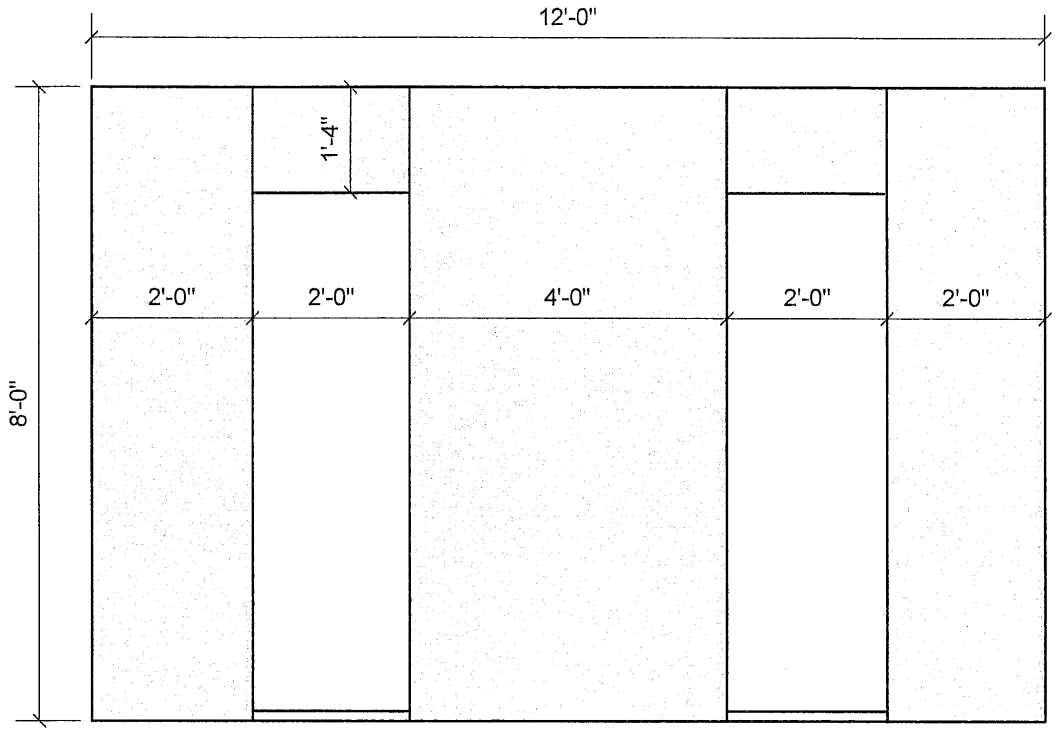


Figure 4. Series 1A: Panel Placement.

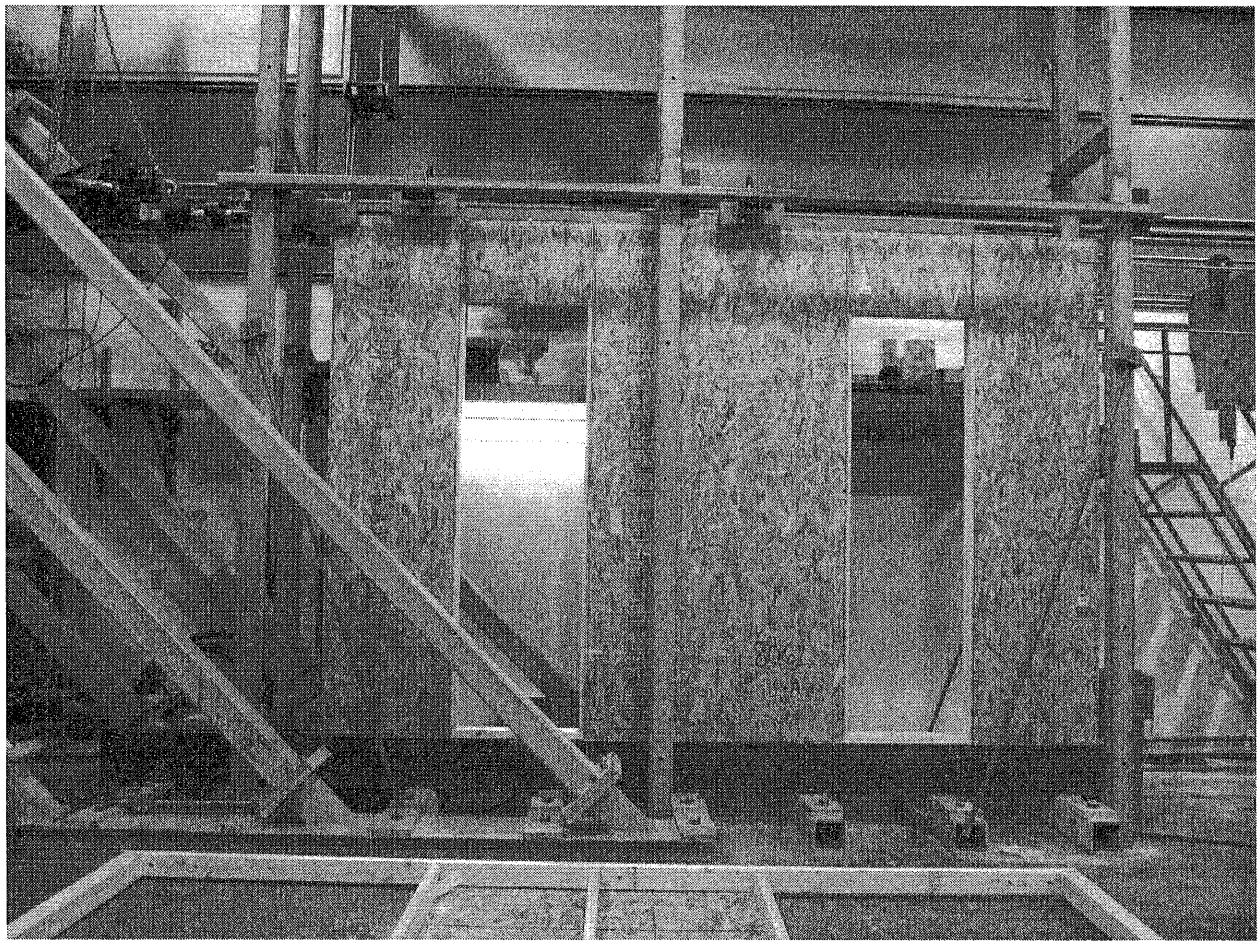


Figure 5. Cyclic Load Test Machine with Test 1A (Test 1B Similar) Wall in Place.

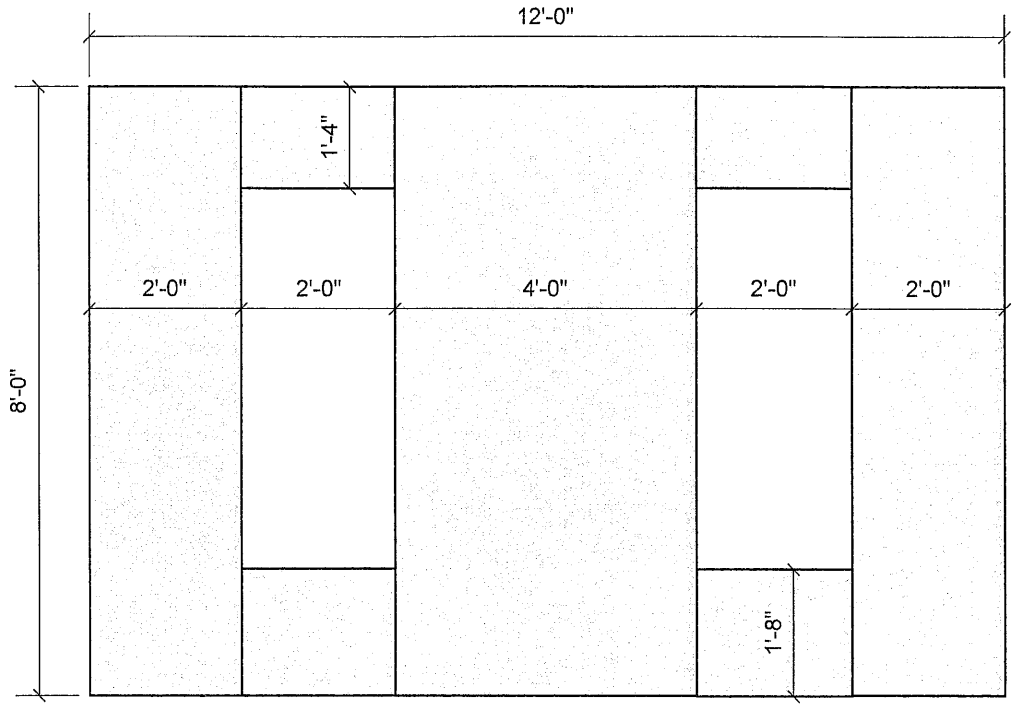


Figure 6. Series 2A: Panel Placement.

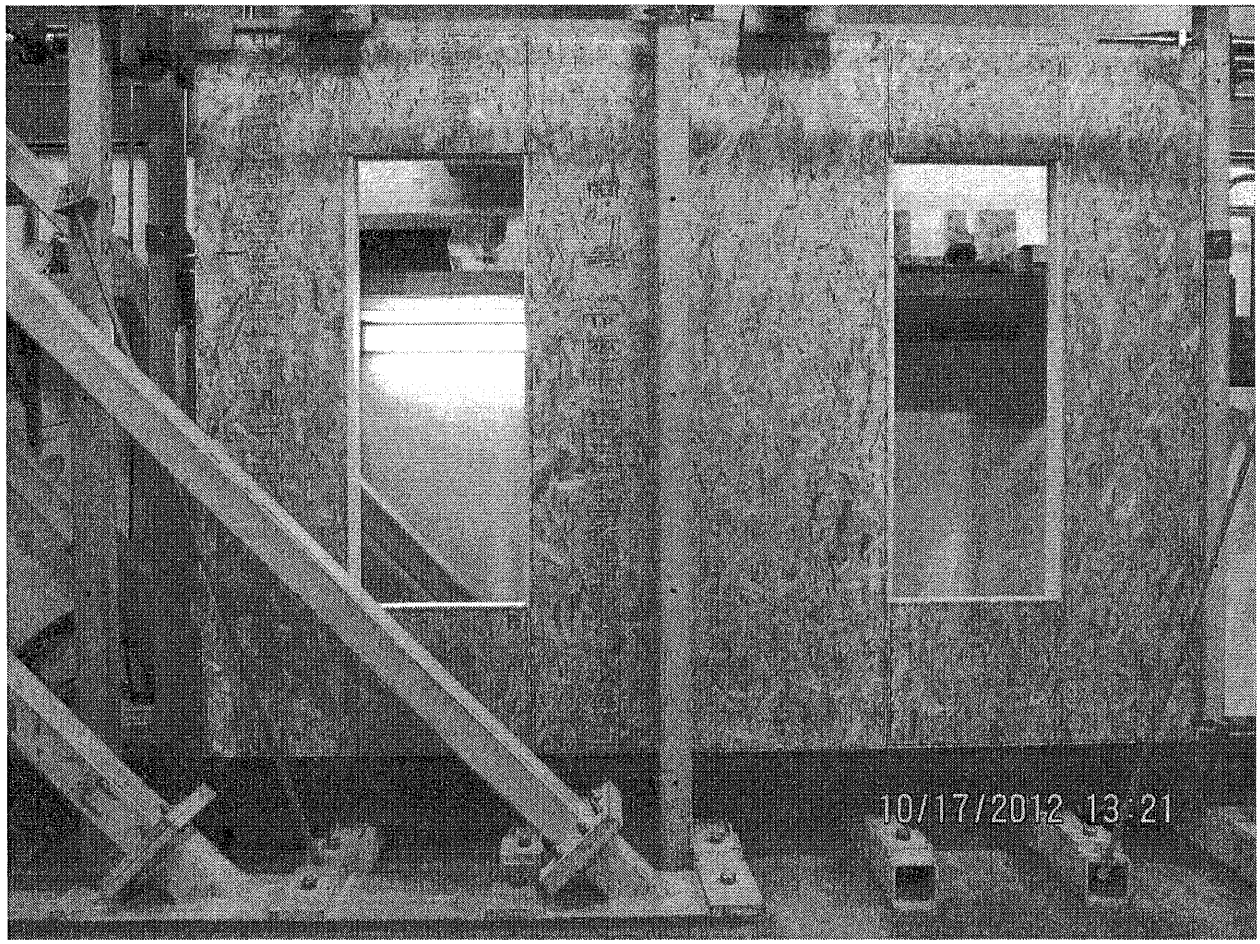


Figure 7. Cyclic Load Test Machine with Test 2A Wall (Test 2B Similar) in Place.

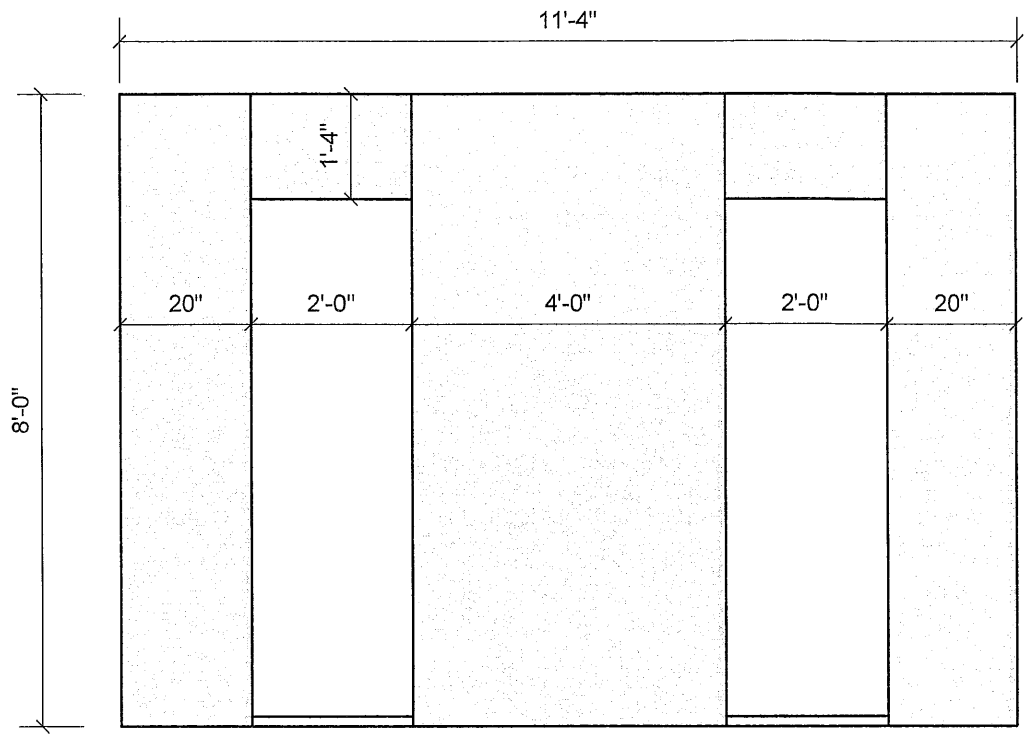


Figure 8. Series 1B: Panel Placement.

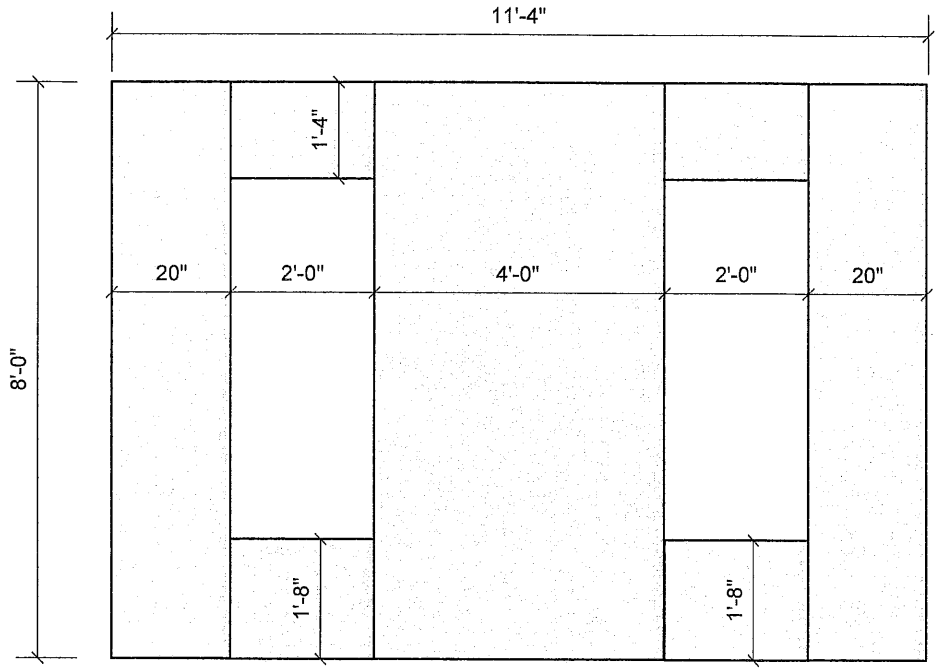


Figure 9. Series 2B: Panel Placement.

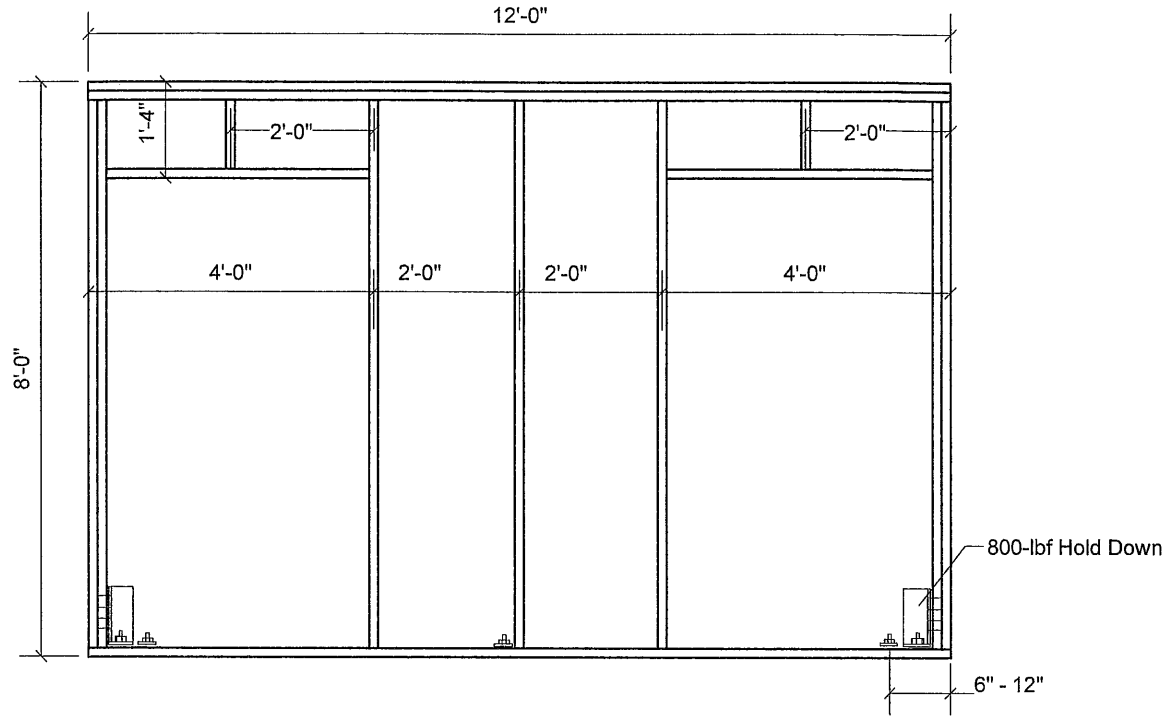


Figure 10. Control: Framing.

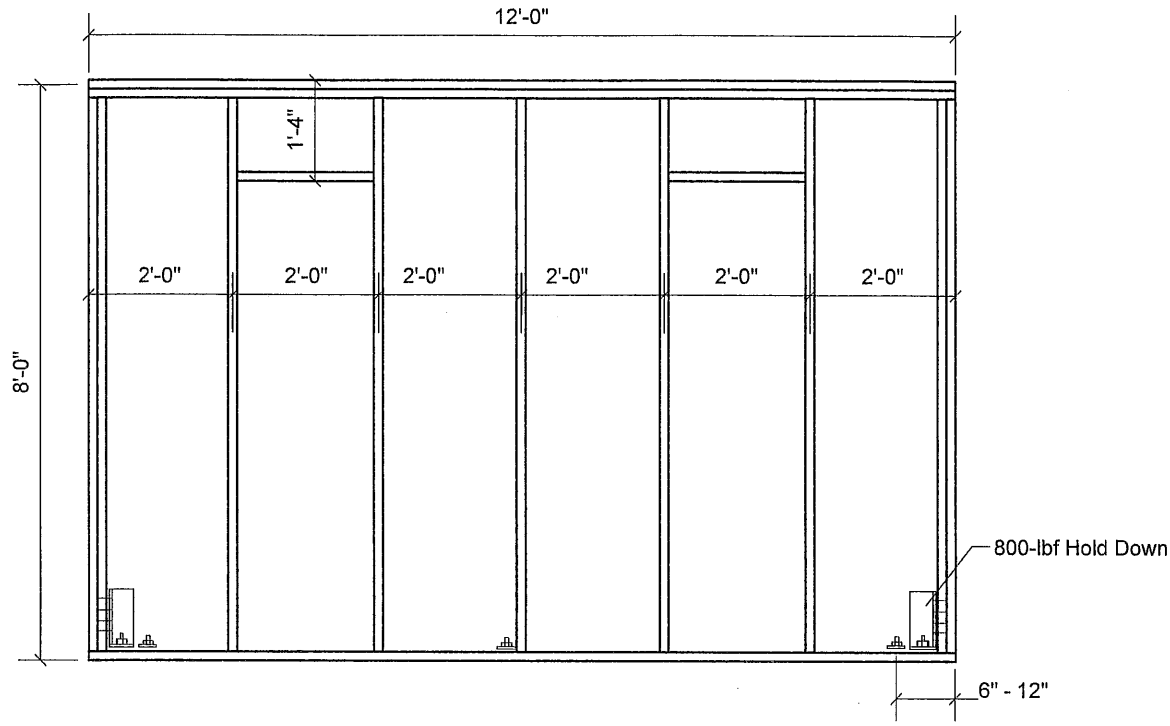


Figure 11. Series 1A: Framing.

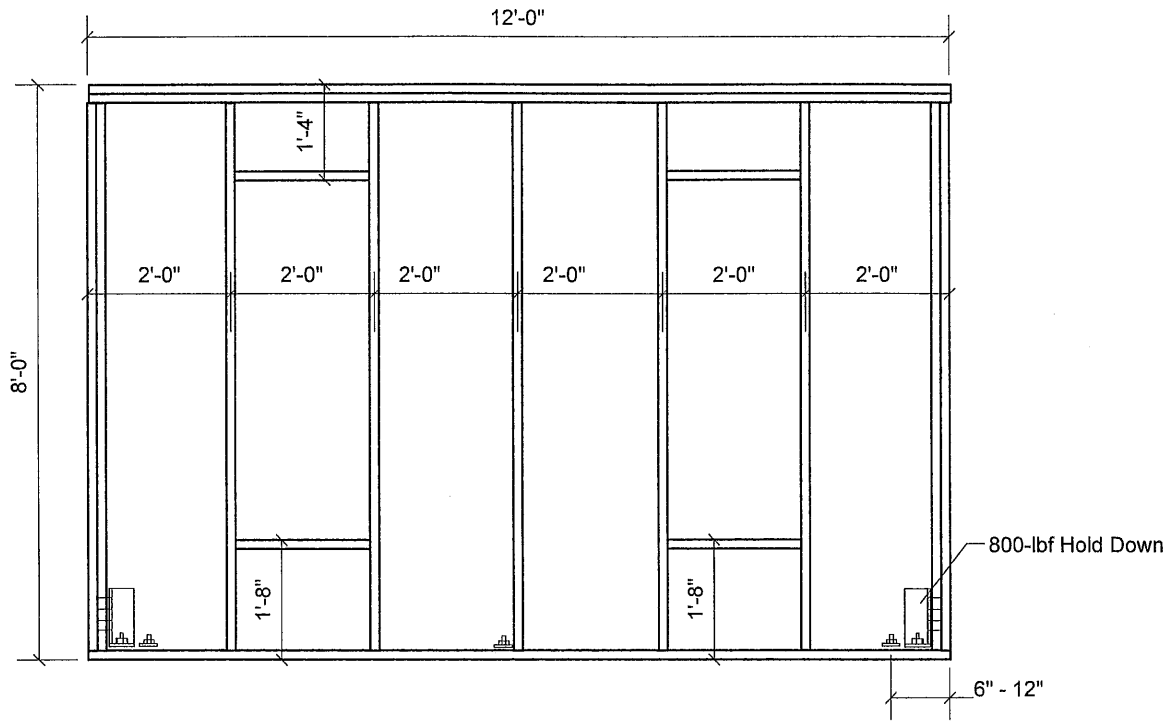


Figure 12. Series 2A: Framing.

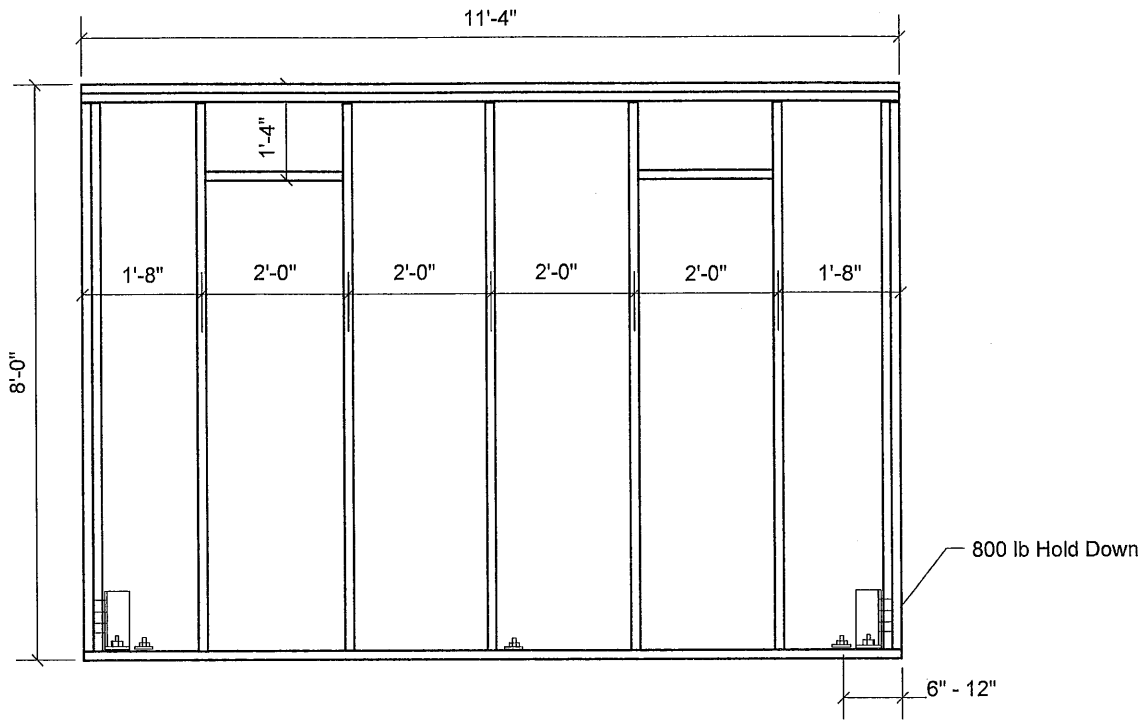


Figure 13. Series 1B: Framing.

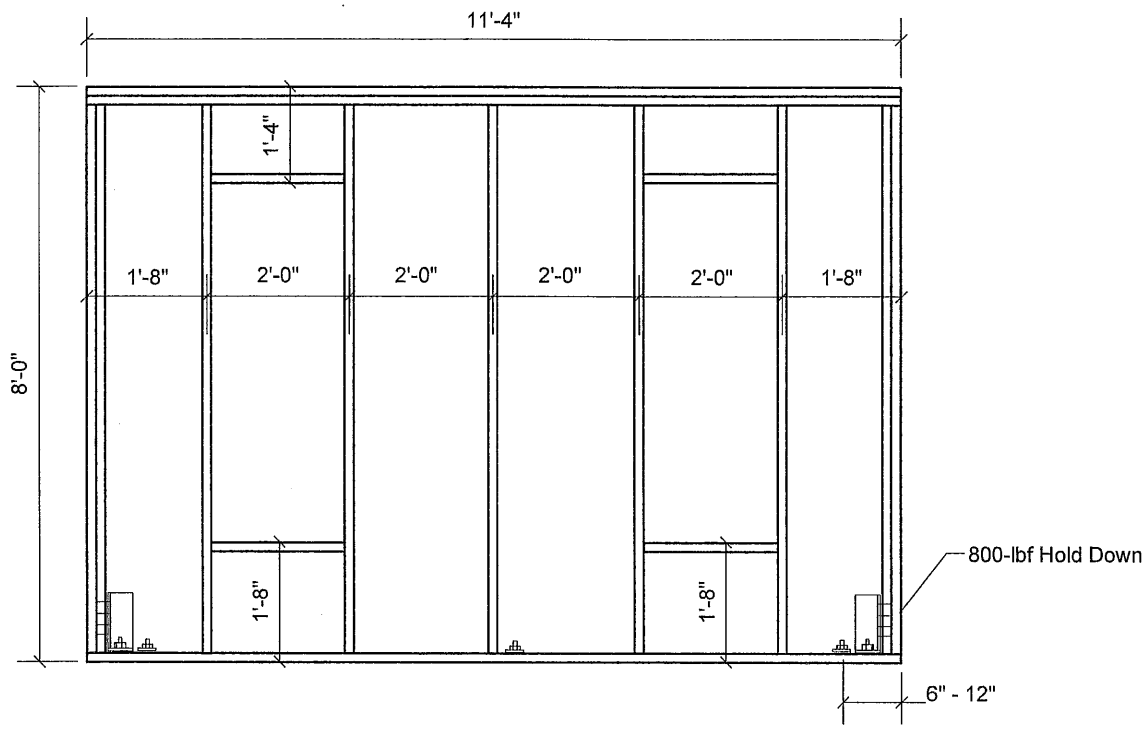


Figure 14. Series 2B: Framing.

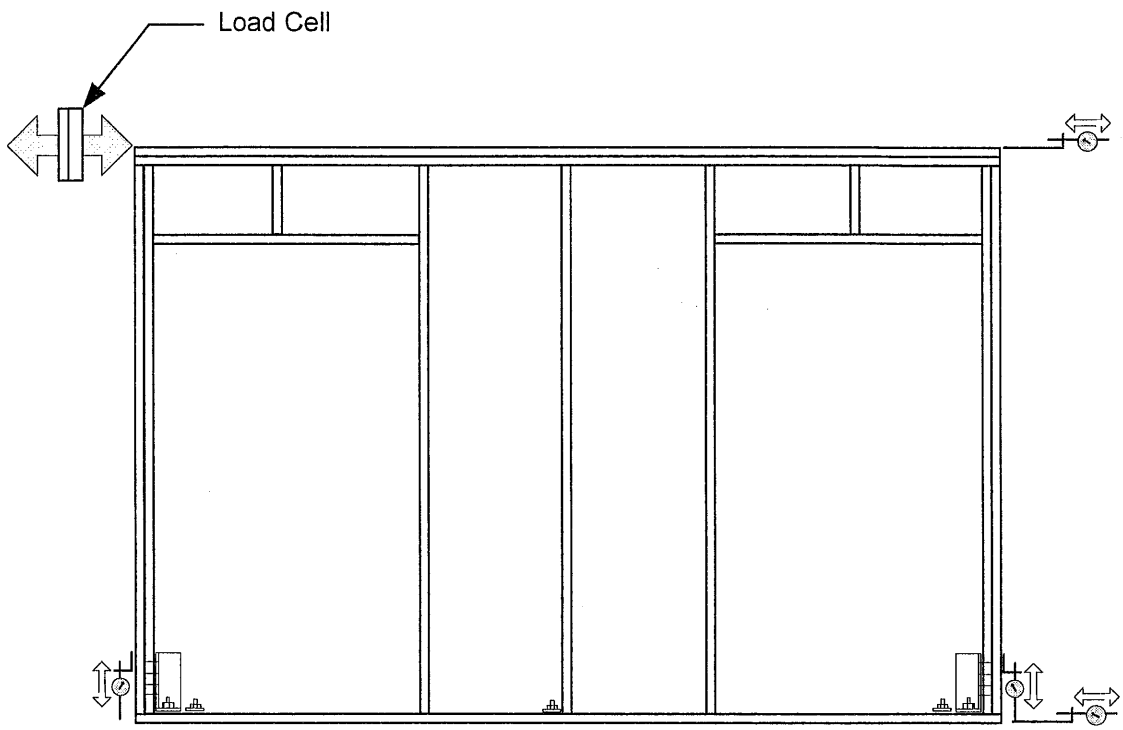
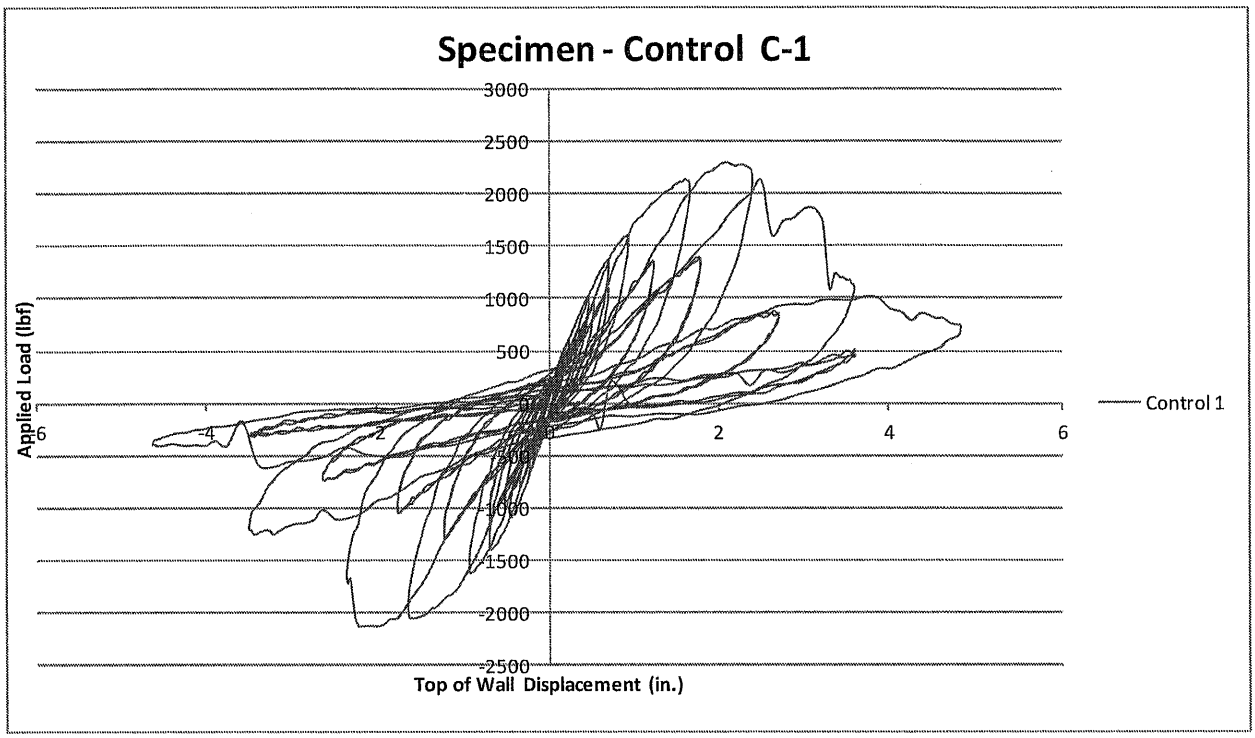
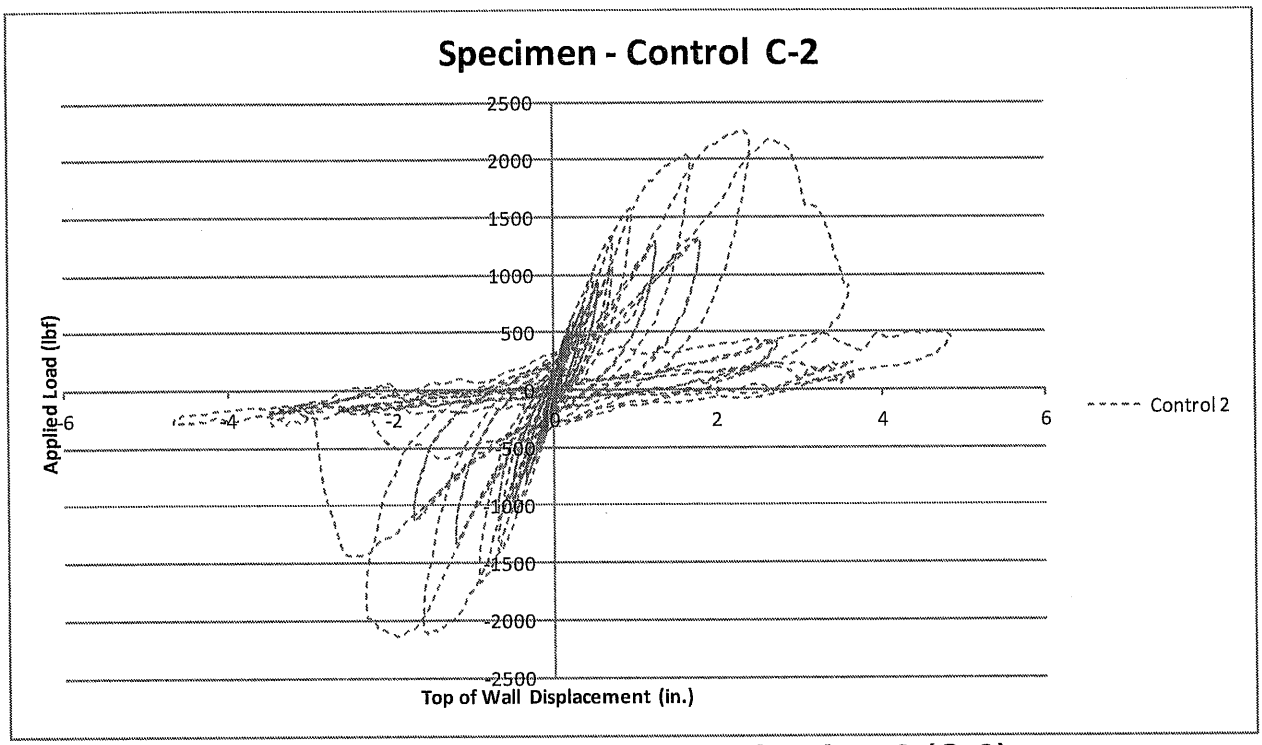


Figure 15. Instrumentation (Typical).

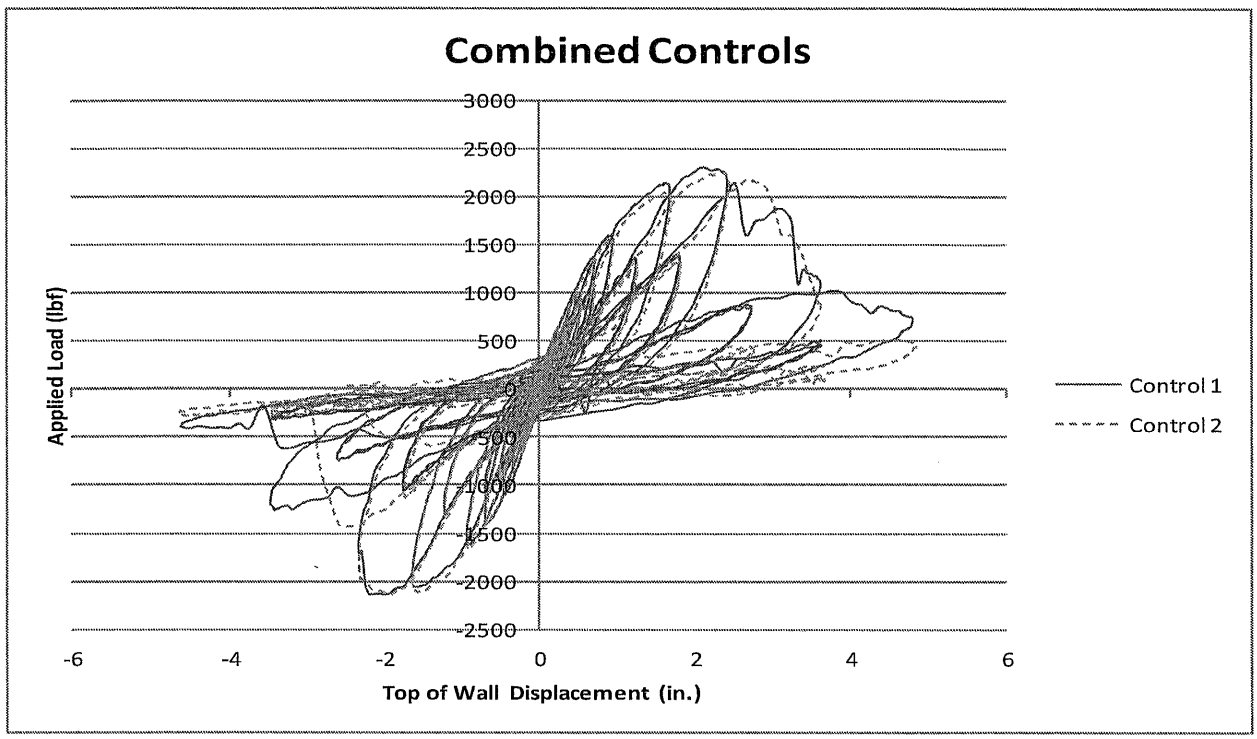
Appendix B: ASTM E2126 Test Plots (15 Pages)



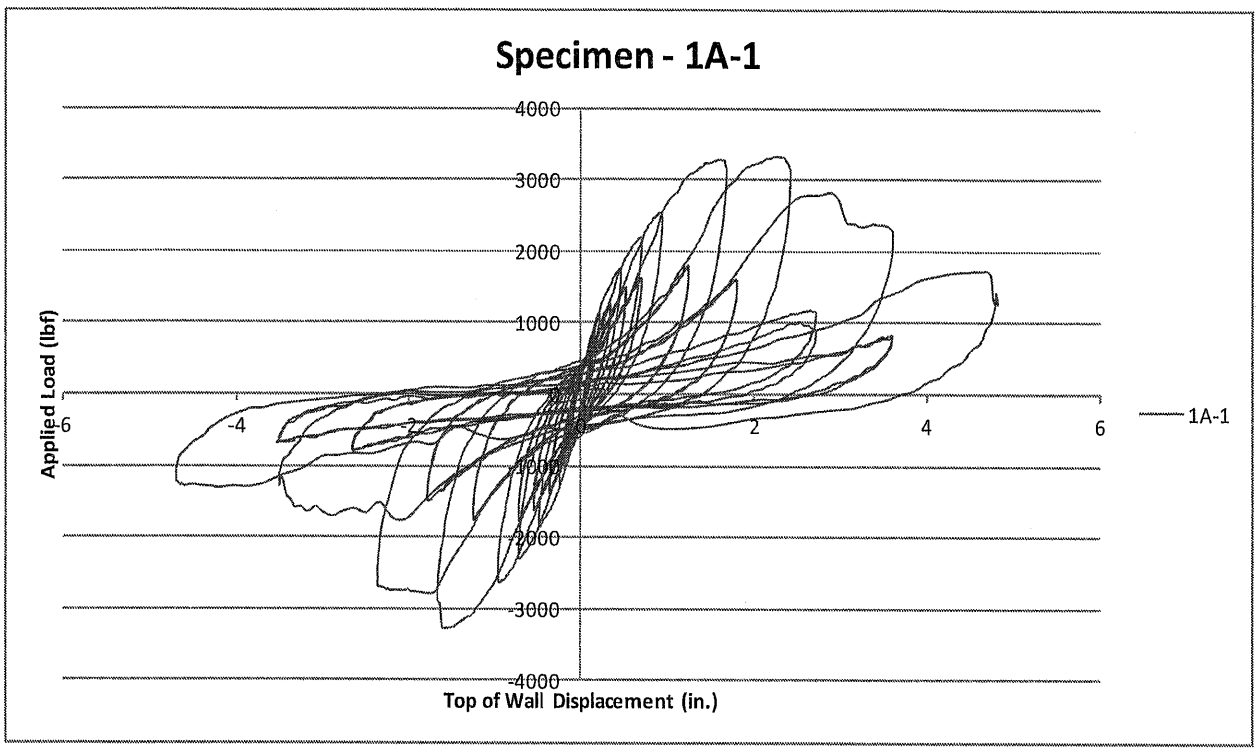
Plot 1. Control Group Test Number 1 (C-1)



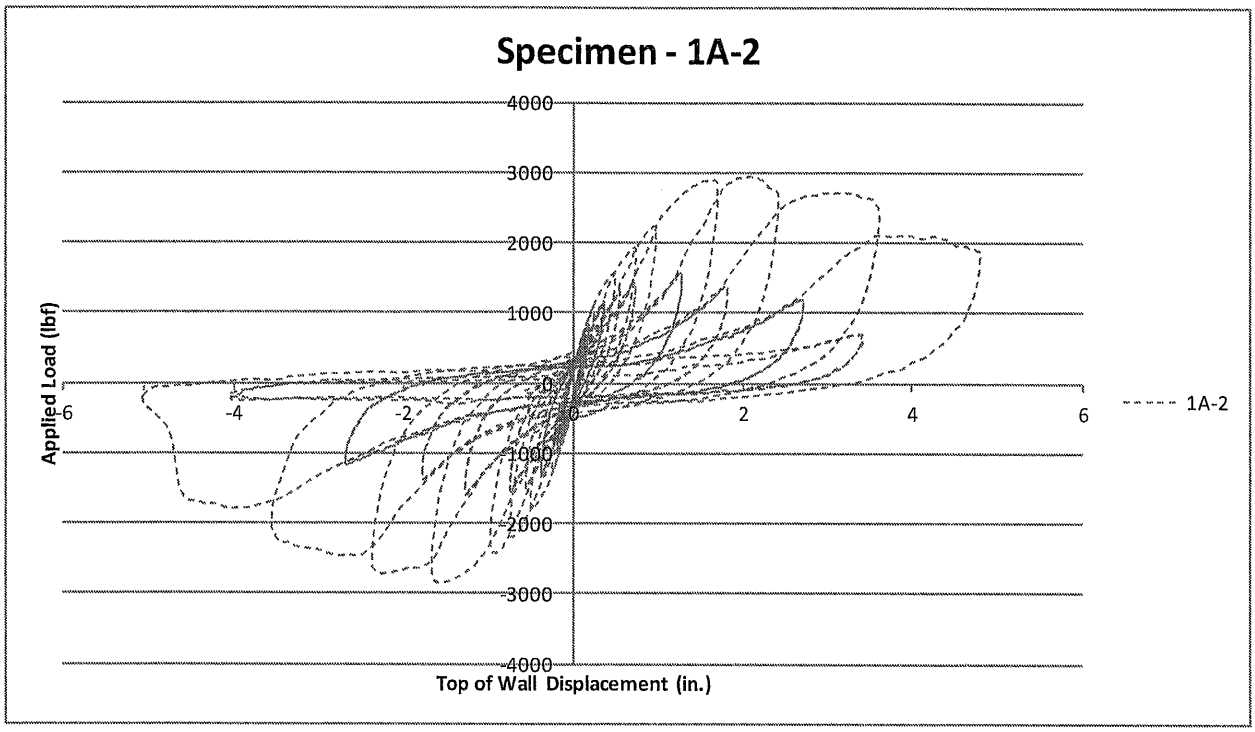
Plot 2. Control Group Test Number 2 (C-2)



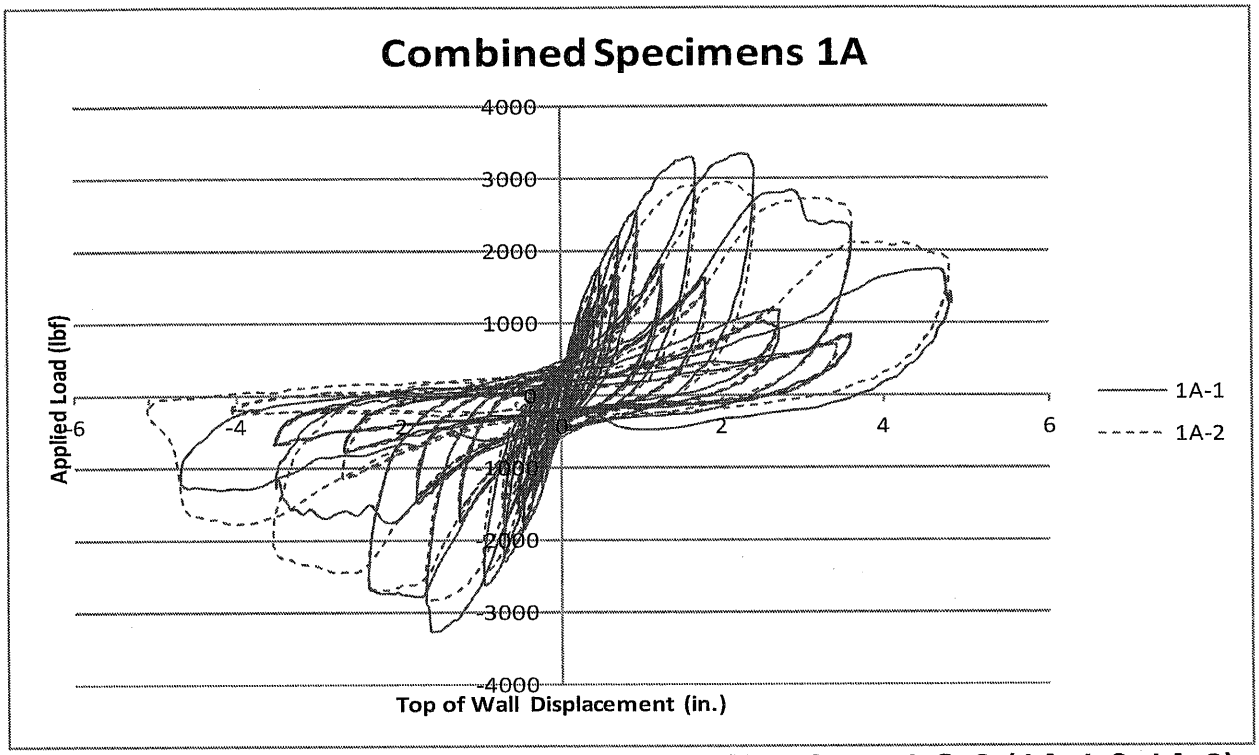
Plot 3. Control Group Test Numbers 1 & 2 (C-1 & C-2)



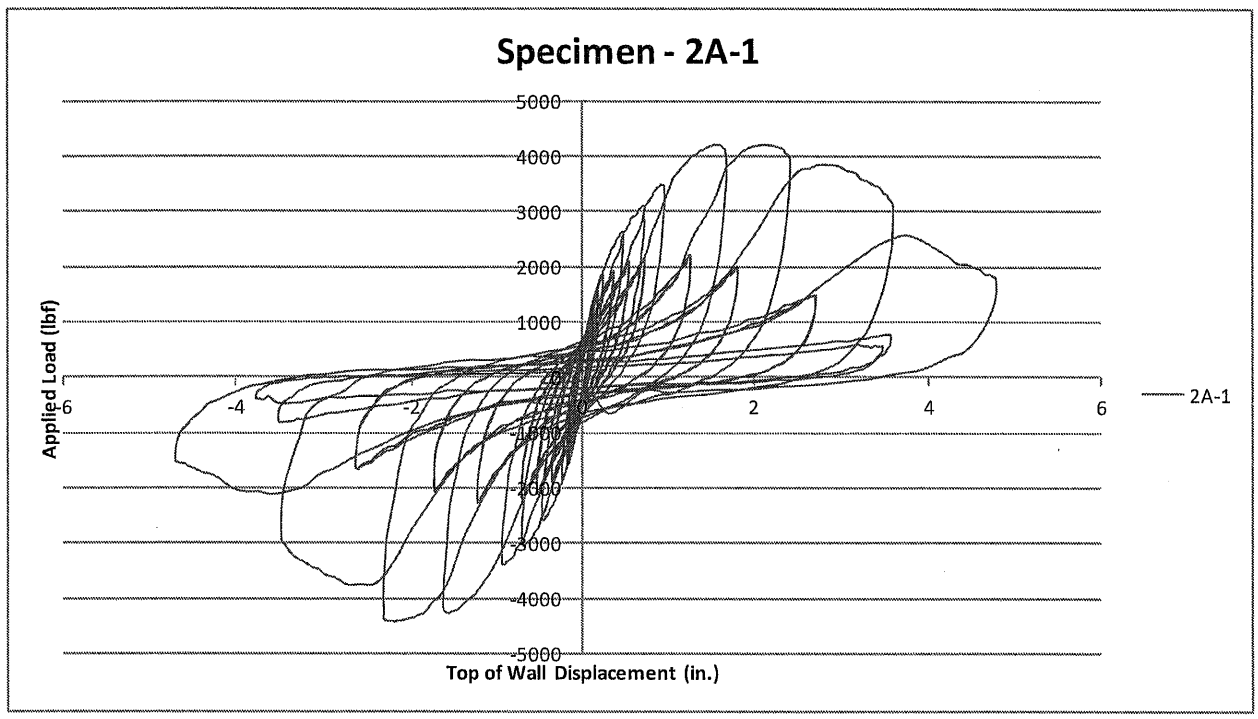
Plot 4. 24″ Element with Man-Door Test Number 1 (1A-1)



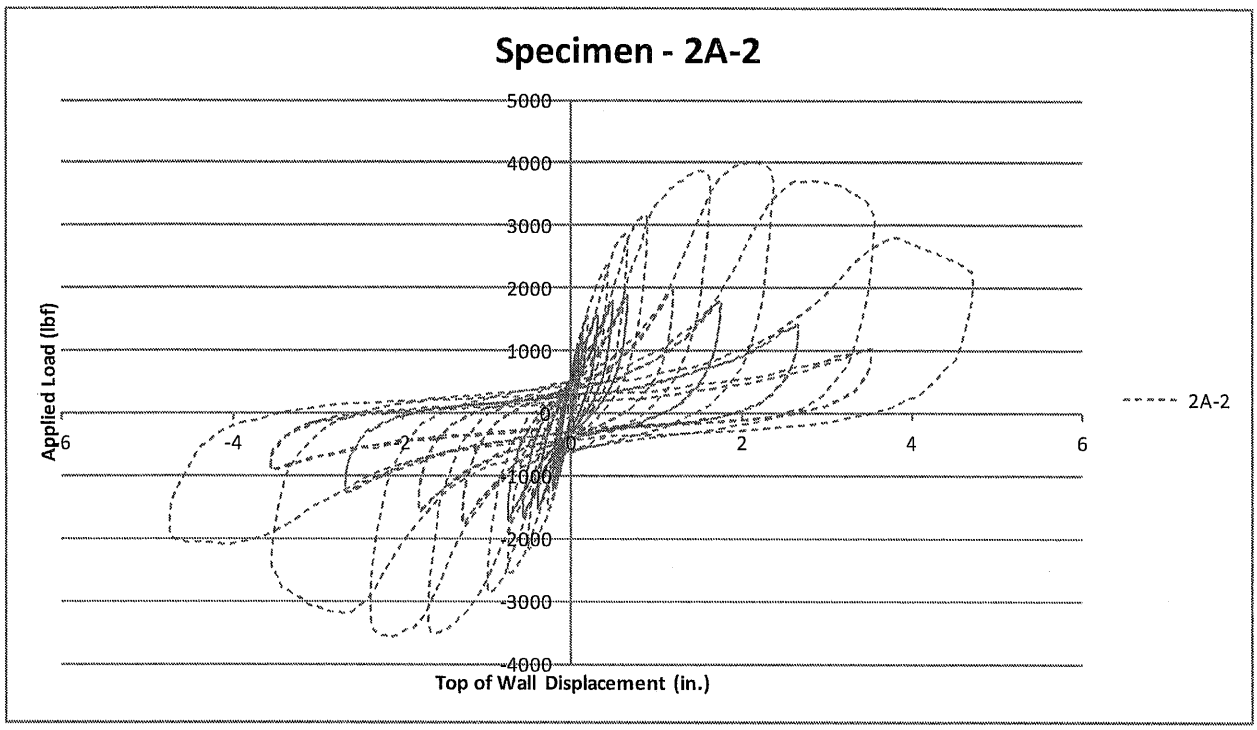
Plot 5. 24″ Element with Man-Door Test Number 2 (1A-2)



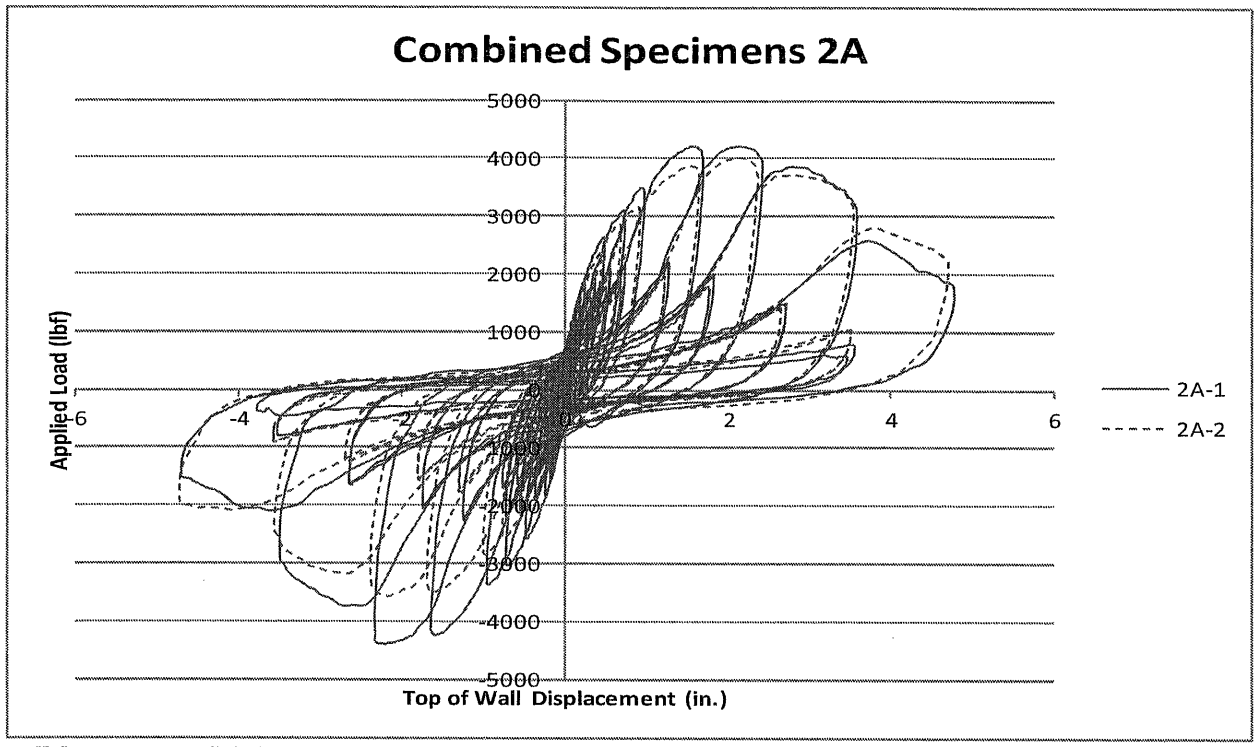
Plot 6. 24" Element with Man-Door Test Numbers 1 & 2 (1A-1 & 1A-2)



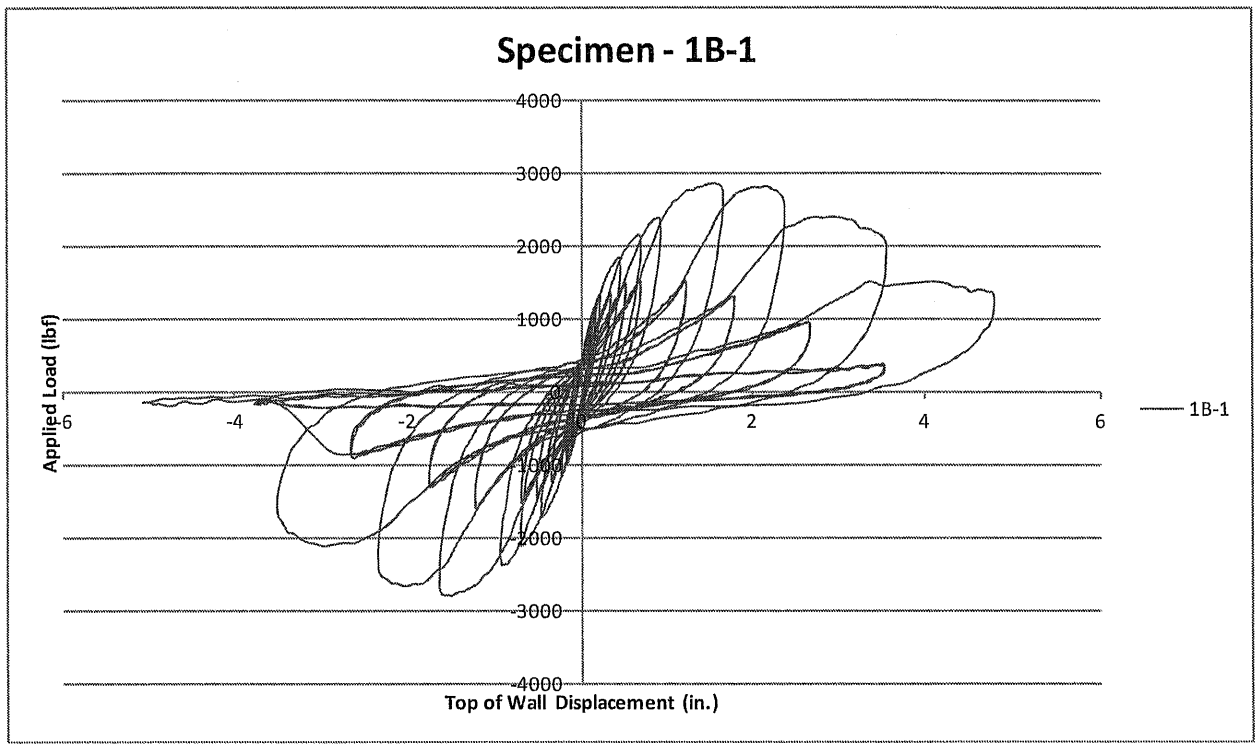
Plot 7. 24" Element with Window Test Number 1 (2A-1)



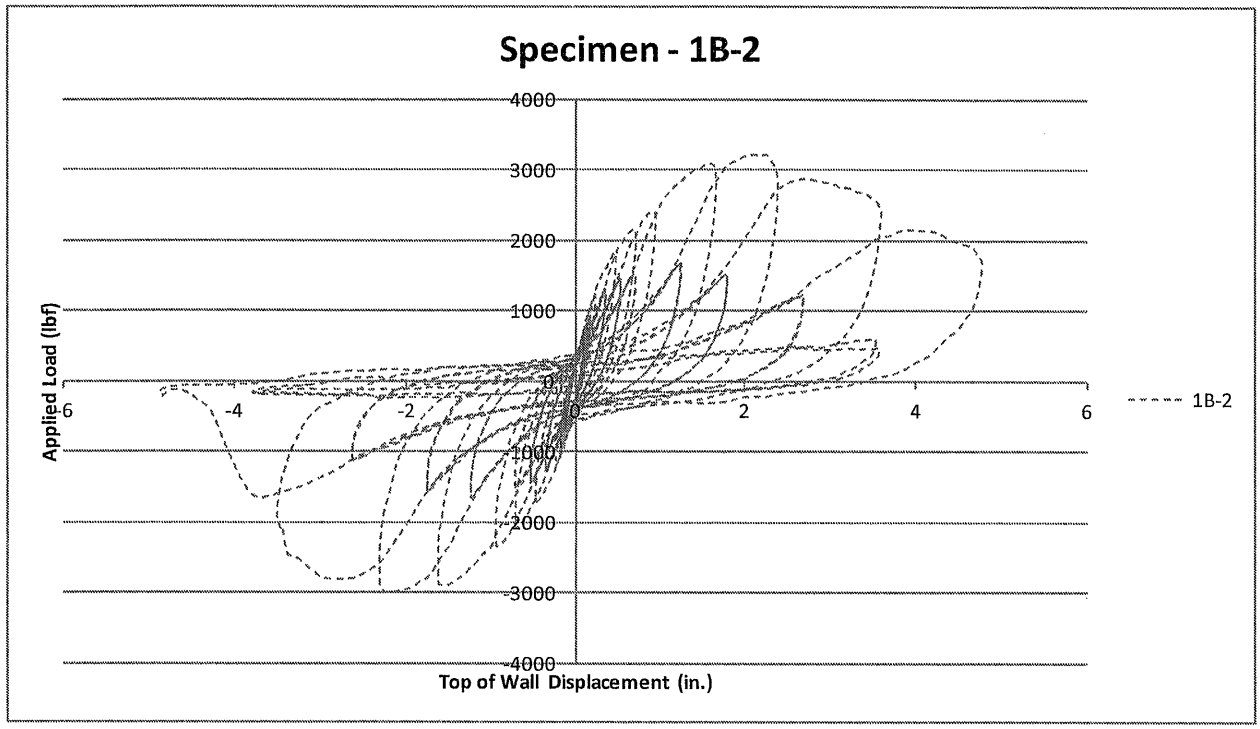
Plot 8. 24" Element with Window Test Number 2 (2A-2)



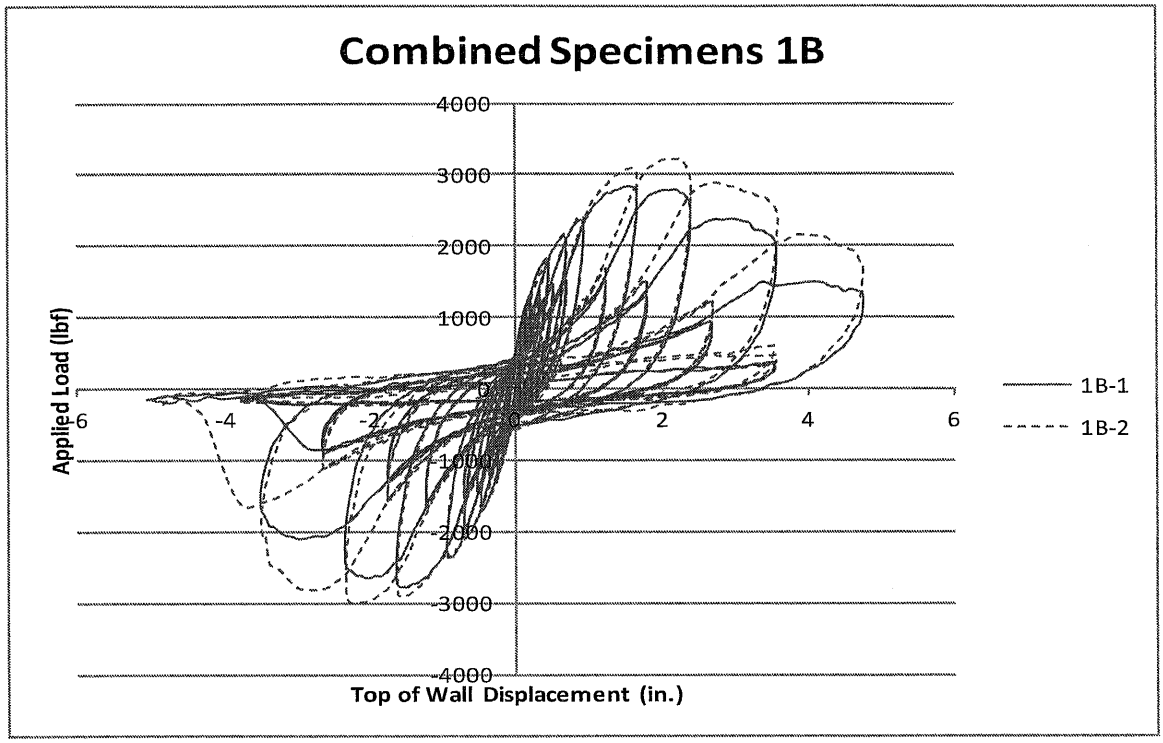
Plot 9. 24″ Element with Window Test Numbers 1 & 2 (2A-1 & 2A-2)



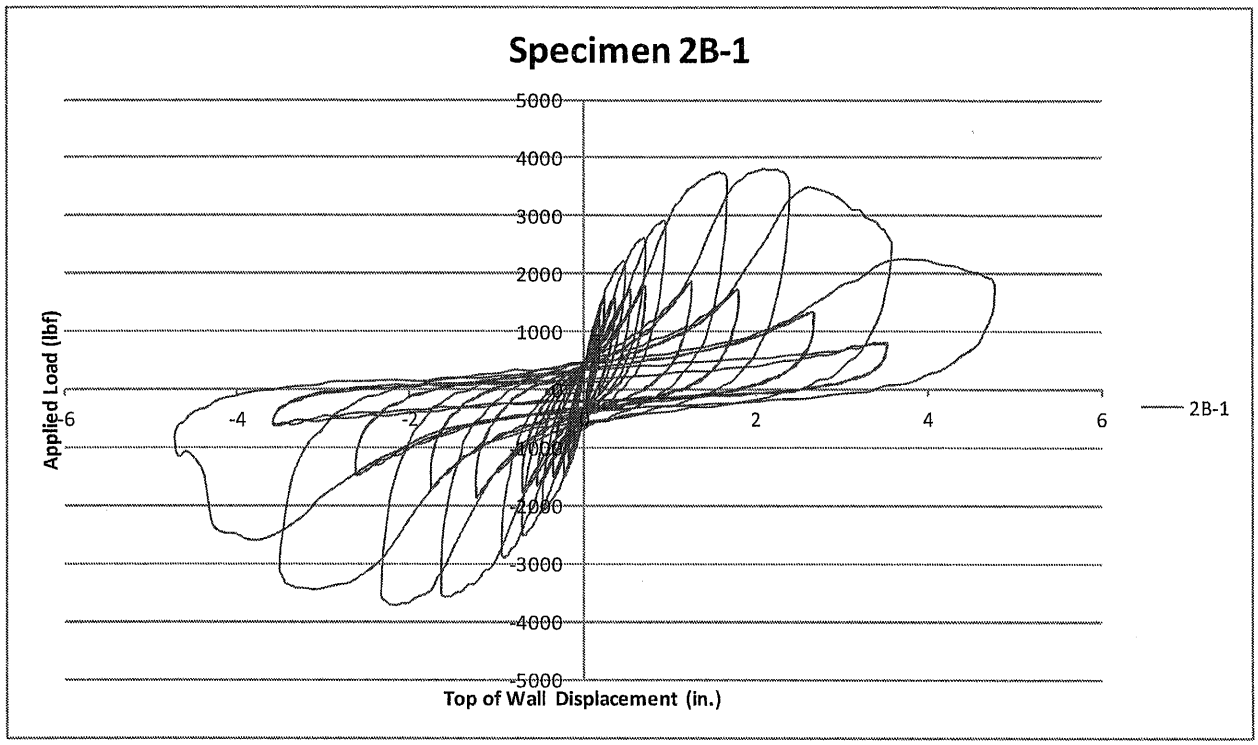
Plot 10. 20″ Element with Man-Door Test Number 1 (1B-1)



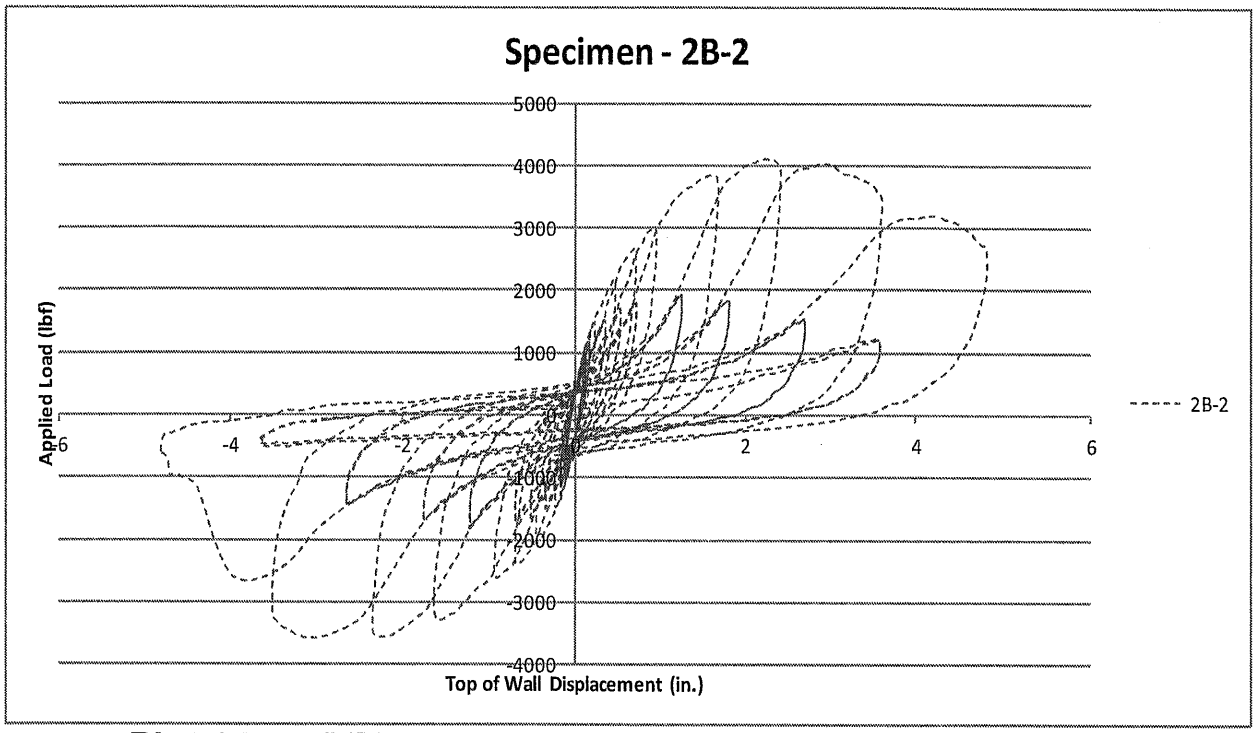
Plot 11. 20″ Element with Man-Door Test Number 2 (1B-2)



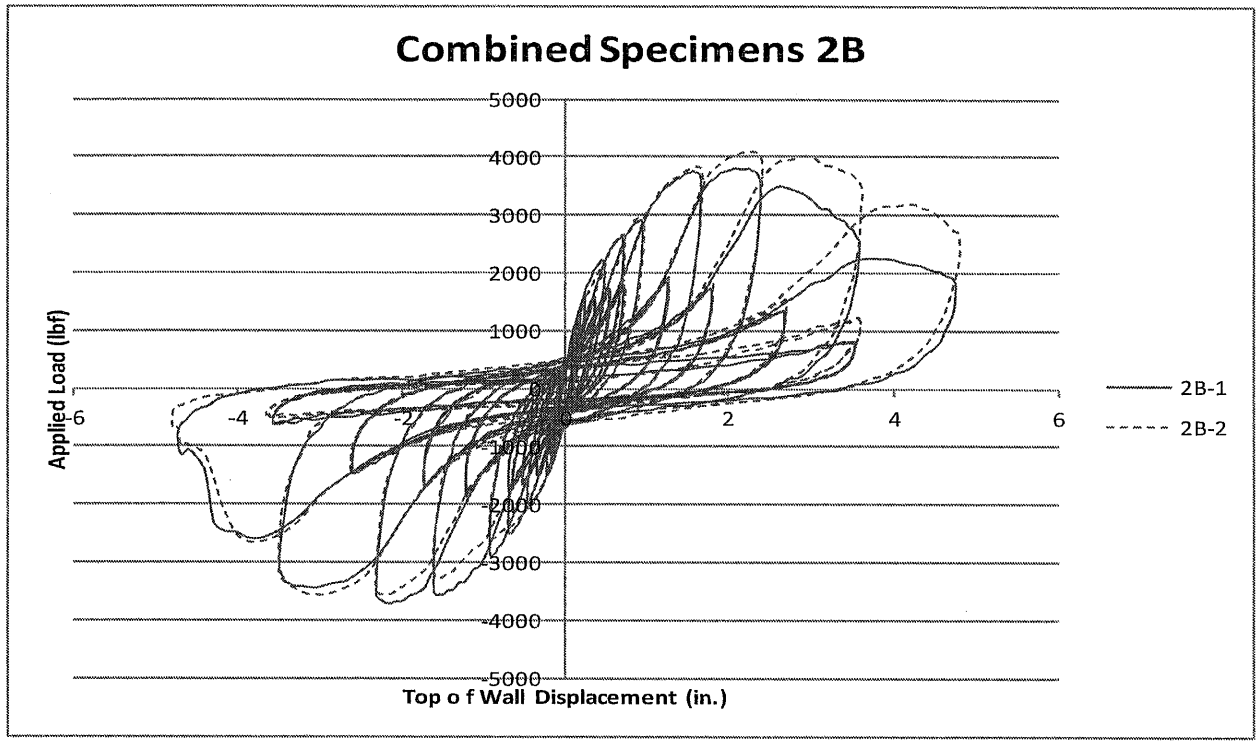
Plot 12. 20″ Element with Man-Door Test Numbers 1 & 2 (1B-1 & 1B-2)



Plot 13. 20″ Element with Window Test Number 1 (2B-1)



Plot 14. 20″ Element with Window Test Number 2 (2B-2)



Plot 15. 20″ Element with Window Test Numbers 1 & 2 (2B-1 & 2B-2)