# APA Report T2012L-16

## *Narrow Wall Bracing*



***by Edward L. Keith, P.E.***
**Technical Services Division**
***August 8, 2012***

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# *Narrow Wall Bracing*


## ***SUMMARY***

This report provides the results of full-scale tests conducted to determine the contribution of full-height braced wall segments in a continuously sheathed wall line when those segments 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 nine-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 segments also added in the wall line. Both door and window elements were tested. The purpose of this testing was to compare the capacity of the control specimens with those having additional narrow-length segments. As both the control and test specimen 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.



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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 combining full-height narrow-length (less than the minimum length required in 2012 IRC Table R602.10.5) wall segments with full-length "qualified" braced wall segments. The problem lies in the understanding that the narrow-length segments are not as stiff as the full-length segments 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 segments.

Similar research has been done for intermittent segments and this has lead to 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 segments compared with intermittent segments makes the partial credit table not applicable to continuously sheathed wall applications. This research is designed to fill this gap for wood structural panels.

This report provides the results of full-scale tests conducted to determine the contribution of full-height braced wall segments in a continuously sheathed wall line when those segments 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 nine-foot-tall walls, based on the fact that this is a common wall height.

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 segments also added in the wall line. Both door and window elements were tested. The purpose of this testing was to compare the capacity of the control specimens with those having additional narrow-length segments. As both the control and test specimen 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 28-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 0.675 inch (0.25*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 segments (see Figures 10 through 14 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, 9 feet in height, SPF #2 or better. All plates were full length (12 feet or 11 feet-4 inches). All framing came from the same bundle. Blocking was used flat wise and attached to framing with two 8d toe-nails (2-1/2 inches by 0.131 inch in diameter) at each end of blocking.

### 3.3 Wall Sheathing

Specimens were sheathed with APA RATED SHEATHING, Performance Category 7/16, 4 foot by 8 foot panels. Note that test specimens are 9-foot high, requiring the use of an 8-foot piece and 1-foot piece of wood structural panel. The horizontal joint of the structural panel was placed at the bottom of the specimen and spliced with a flat 2x4 splice cut from #2 or better SPF and nailing from adjoining panel edges utilized the panel edge-nail spacing. All panels were taken from the same unit.

### 3.4 Fastening

- Panels were fastened with 6d (2 inches x 0.113 inch in diameter) spaced at 6 inches on center around the panel perimeter, at all blocking, and at 12 inches on center in the field of the panel. All nails were sourced from the same box.
- 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 sinkers (3-1/4 inches x 0.148 inch in diameter).

### 3.5 Anchor bolts

Each wall was attached to the test frame with two 5/8-inch anchor bolts placed within 6-12 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 each 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 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 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 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 segment. As the control was fabricated to model a continuously-sheathed wall segment, both sides of the center braced wall panel were framed (see Appendix A, Figure 10) and sheathed as for 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 0.675 inches 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 0.675 inches 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 0.675-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 segments. 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 segments 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.

A flexible load head was used along with the top of each wall specimen.

## 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 – Deflection-Based ASD - Method AC130**

| Test Number | ASD Method AC130 | | | Average | | | $R^c$ (ASD Method AC130) |
|---|---|---|---|---|---|---|---|
| | Load at 0.675″ ($V_{LRFD}$[a]) (lbf) | $V_{LRFD}$/1.4 Load ($V_{ASD}$) (lbf) | Defl. at $V_{ASD}$[b] (in.) | Load at 0.675″ ($V_{LRFD}$[a]) (lbf) | $V_{LRFD}$/1.4 Load ($V_{ASD}$) (lbf) | Defl. at $V_{ASD}$[b] (in.) | |
| C-1 | 1,249 | 892 | 0.323 | 1,293 | 924 | 0.354 | --- |
| C-2 | 1,337 | 955 | 0.384 | | | | |
| 1A-1 | 2,017 | 1,441 | 0.230 | 2,173 | 1,553 | 0.316 | 0.68 |
| 1A-2 | 2,329 | 1,664 | 0.402 | | | | |
| 2A-1 | 2,504 | 1,789 | 0.369 | 2,719 | 1,942 | 0.310 | 1.10 |
| 2A-2 | 2,933 | 2,095 | 0.251 | | | | |
| 1B-1 | 1,930 | 1,379 | 0.245 | 1,897 | 1,355 | 0.234 | 0.56 |
| 1B-2 | 1,864 | 1,331 | 0.222 | | | | |
| 2B-1 | 2,530 | 1,807 | 0.318 | 2,419 | 1,728 | 0.279 | 1.04 |
| 2B-2 | 2,308 | 1,648 | 0.240 | | | | |

[a] $V_{LRFD}$ = shear force at a deflection of 0.025 x H / $C_d$ = 0.675 for an H of 108″ 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.

**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 | 2.88 | 2,113 | 2.80 | 2,131 | 853 | 1.00 | 1.00 |
| C-2 | 2.71 | 2,150 | | | | | |
| 1A-1 | 1.90 | 2,964 | 1.88 | 3,128 | 1,251 | 0.67 | 1.47 |
| 1A-2 | 1.87 | 3293 | | | | | |
| 2A-1 | 1.88 | 3,624 | 2.11 | 3,988 | 1,595 | 0.75 | 1.87 |
| 2A-2 | 2.33 | 4,353 | | | | | |
| 1B-1 | 1.83 | 3,207 | 1.83 | 3,160 | 1,264 | 0.65 | 1.48 |
| 1B-2 | 1.82 | 3,112 | | | | | |
| 2B-1 | 2.76 | 4,442 | 2.29 | 4,418 | 1,767 | 0.82 | 2.07 |
| 2B-2 | 1.82 | 4,395 | | | | | |

[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 9-foot tall wall contributes from 68 percent (0.68 X 24 = 16.3 inches) to 110 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 9-foot tall wall contributes from 56 percent (0.56 X 20 = 11.2 inches) to 104 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.

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 better than the Controls by a significant margin in both design strength and stiffness, regardless of the opening size.

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 for 9-foot walls[a]**

| Bracing Method | Wall Height (feet) | 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 | 9 | 24 | ≤60 | 24 |
| | | | 64 | 22 |
| | | | 68 | 21 |
| | | | 72 | 19 |
| | | | 76 | 18 |
| | | | 80 | 16 |
| | | 20 | ≤60 | 20 |
| | | | 64 | 18 |
| | | | 68 | 16 |
| | | | 72 | 15 |
| | | | 76 | 13 |
| | | | 80 | 11 |

[a] Linear interpolation shall be permitted.

## *6. REFERENCES*

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.**

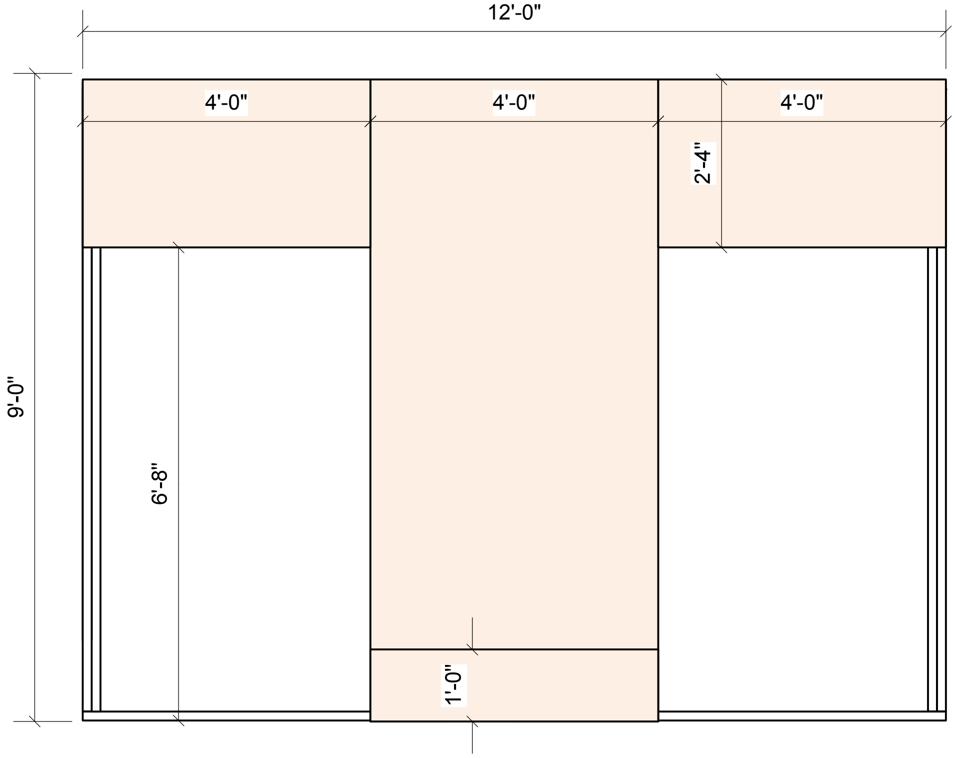



**Figure 2. Control: Panel Placement.**

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

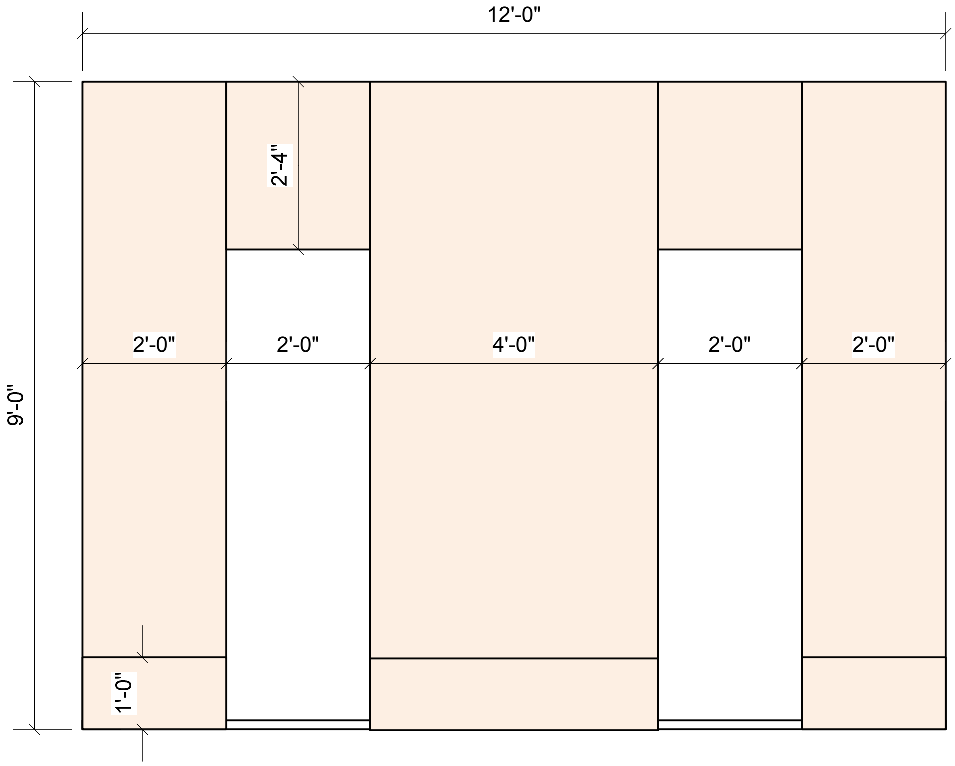



**Figure 4. Series 1A: Panel Placement.**

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

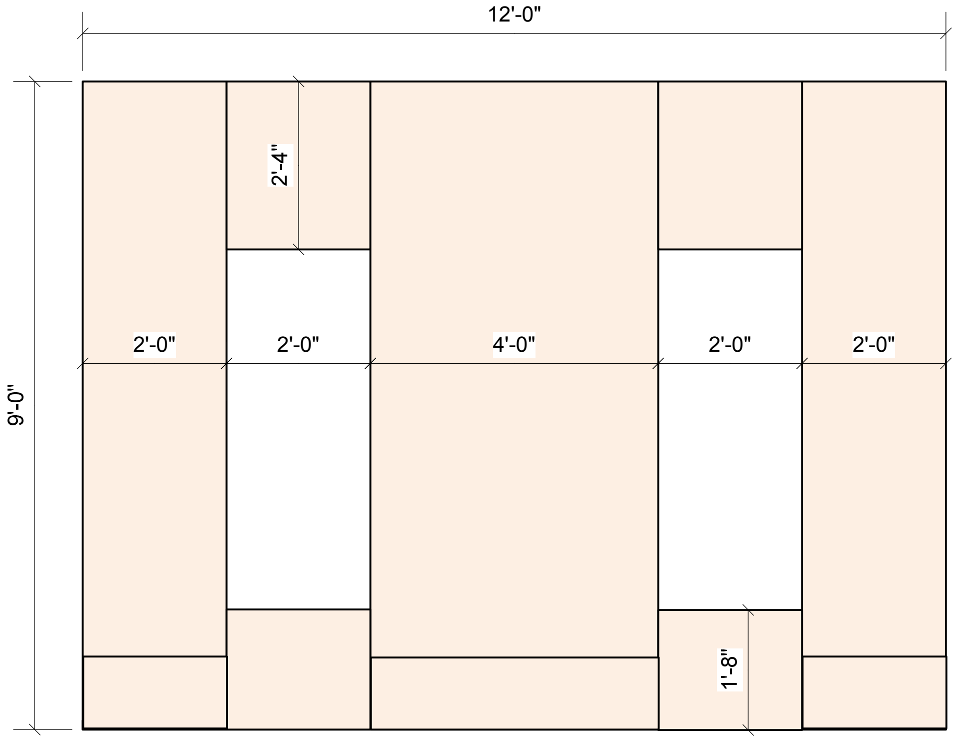



**Figure 6. Series 2A: Panel Placement.**

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

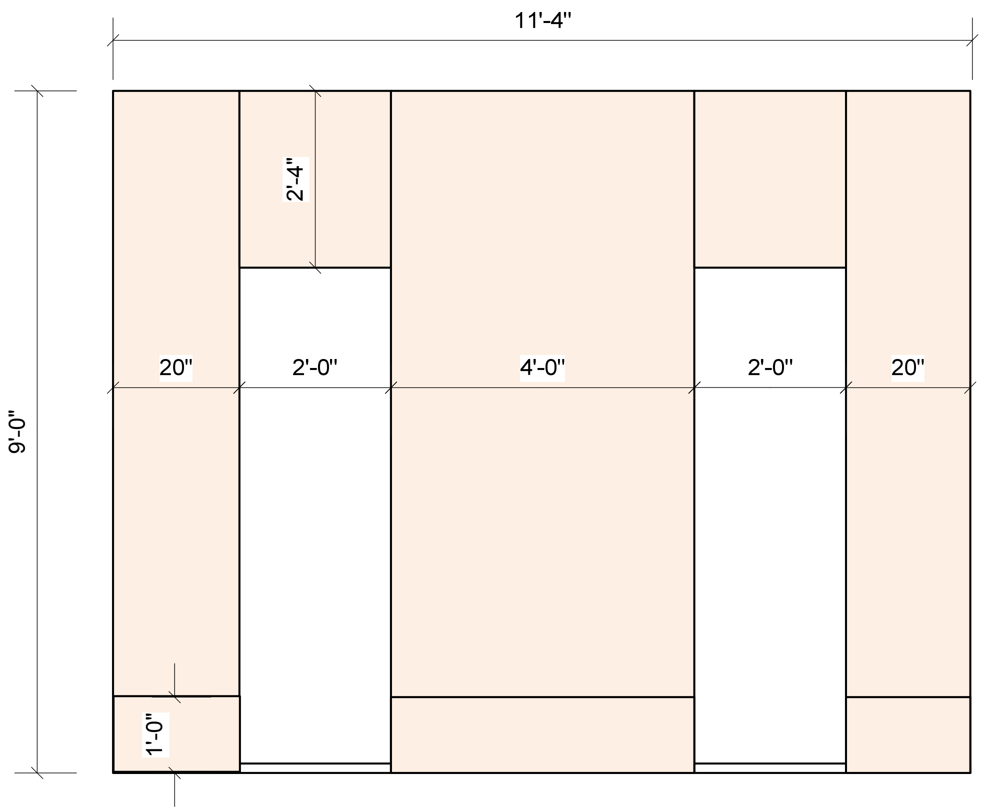



**Figure 8. Series 1B: Panel Placement.**

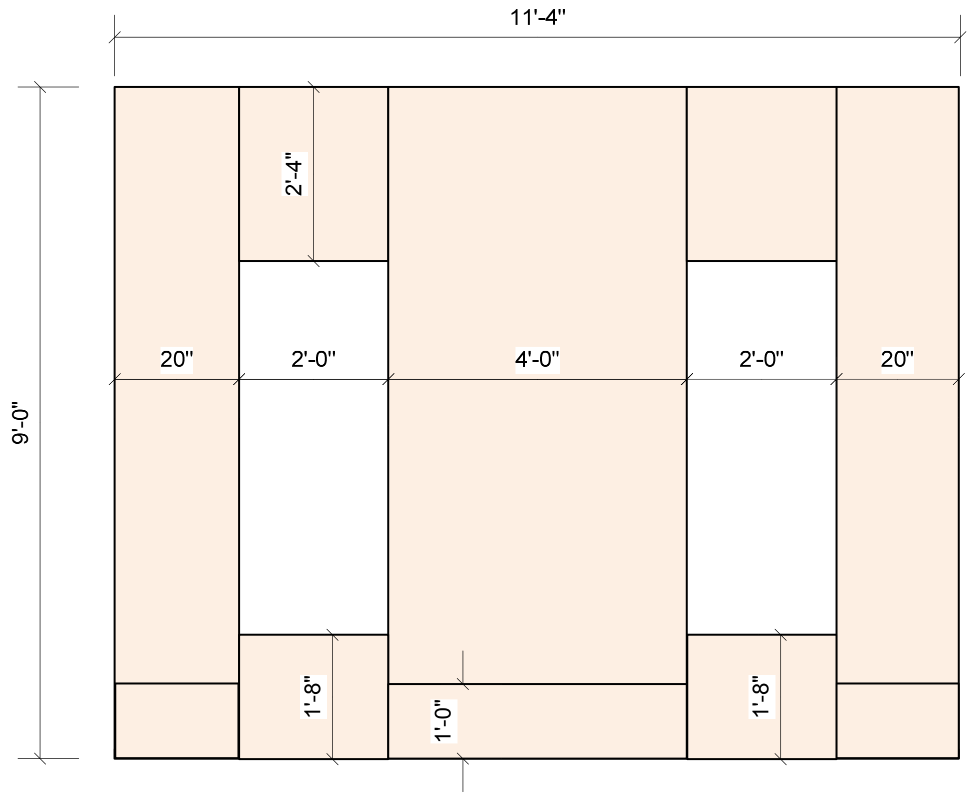



**Figure 9. Series 2B: Panel Placement.**

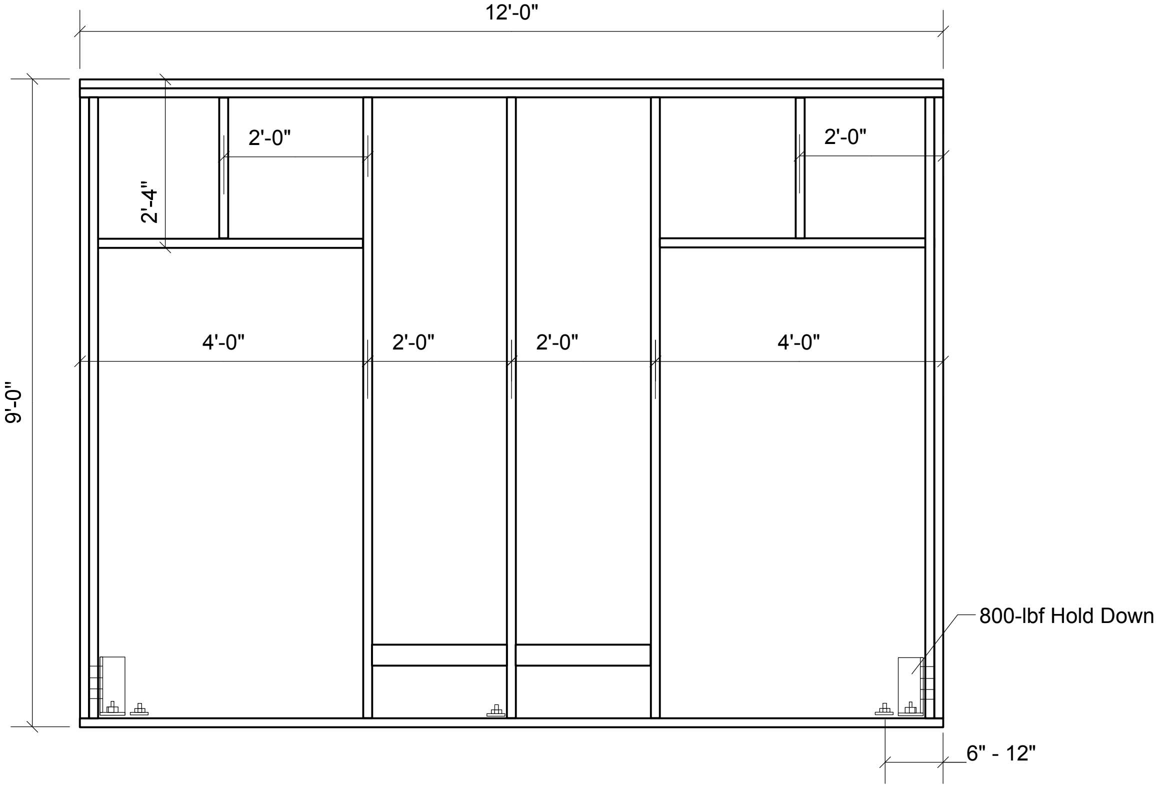



**Figure 10. Control: Framing.**

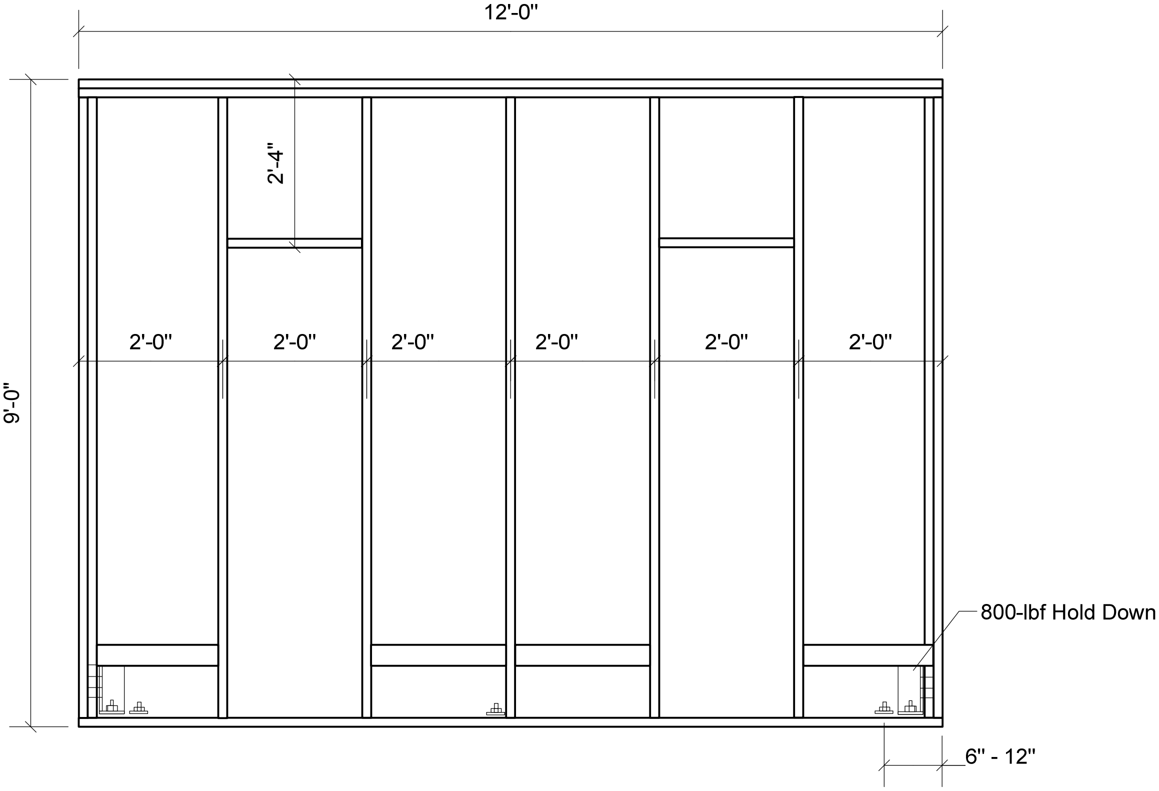



**Figure 11. Series 1A: Framing.**

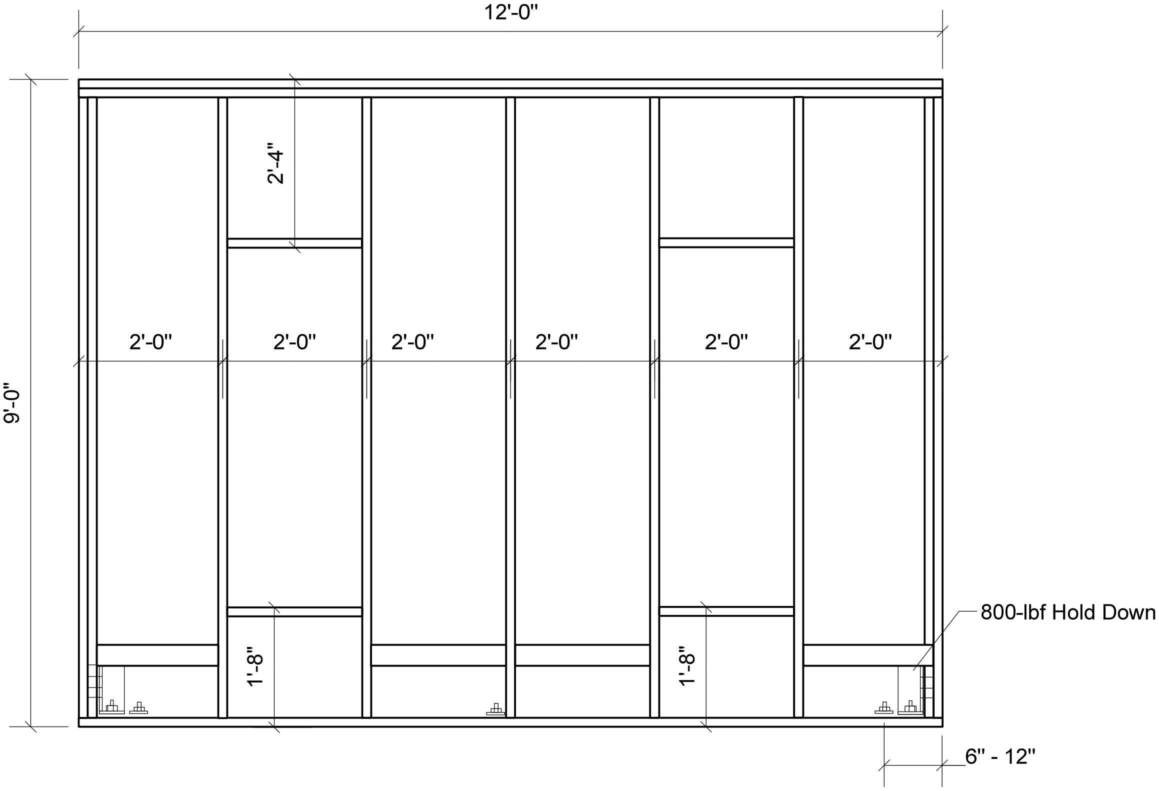



**Figure 12. Series 2A: Framing.**

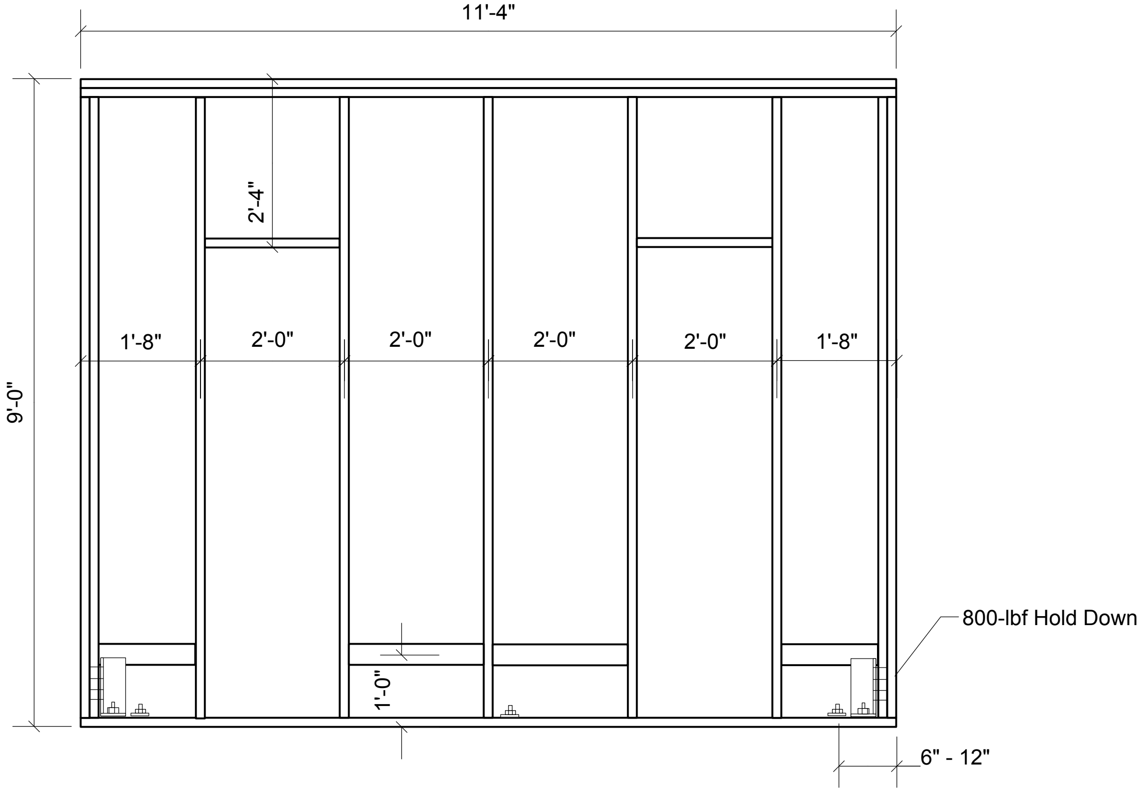



**Figure 13. Series 1B: Framing.**

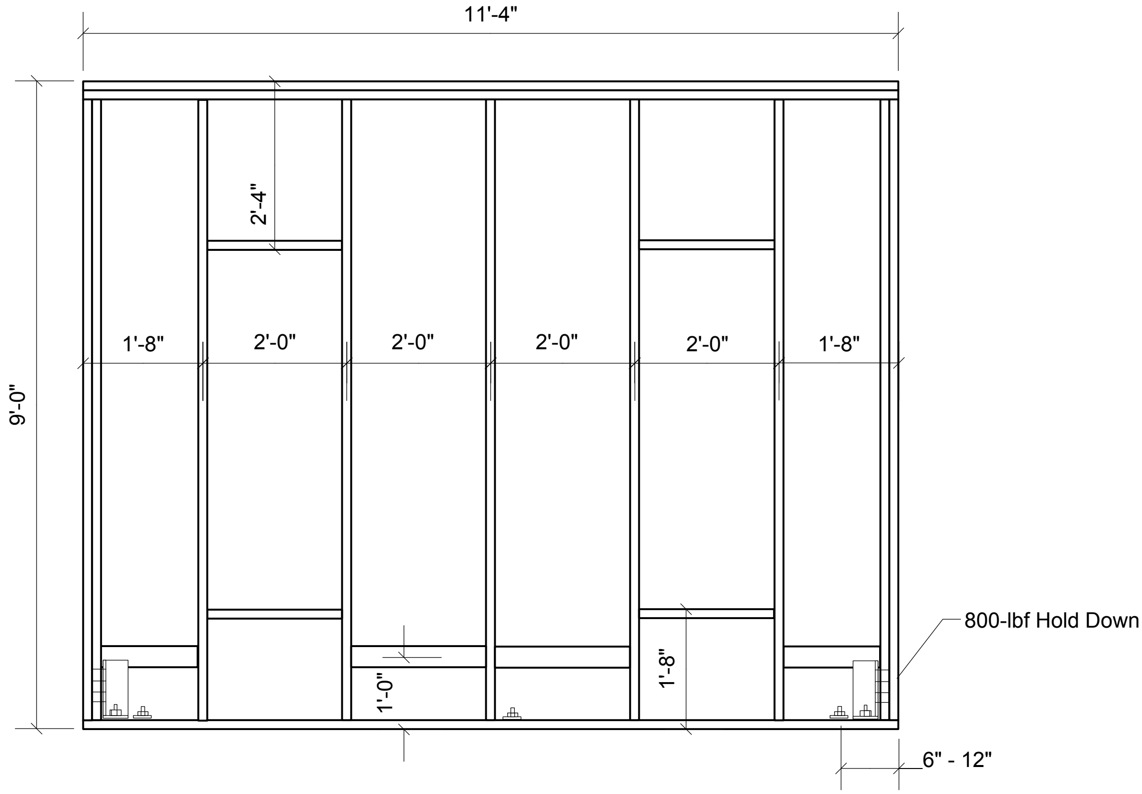



**Figure 14.  Series 2B:  Framing.**

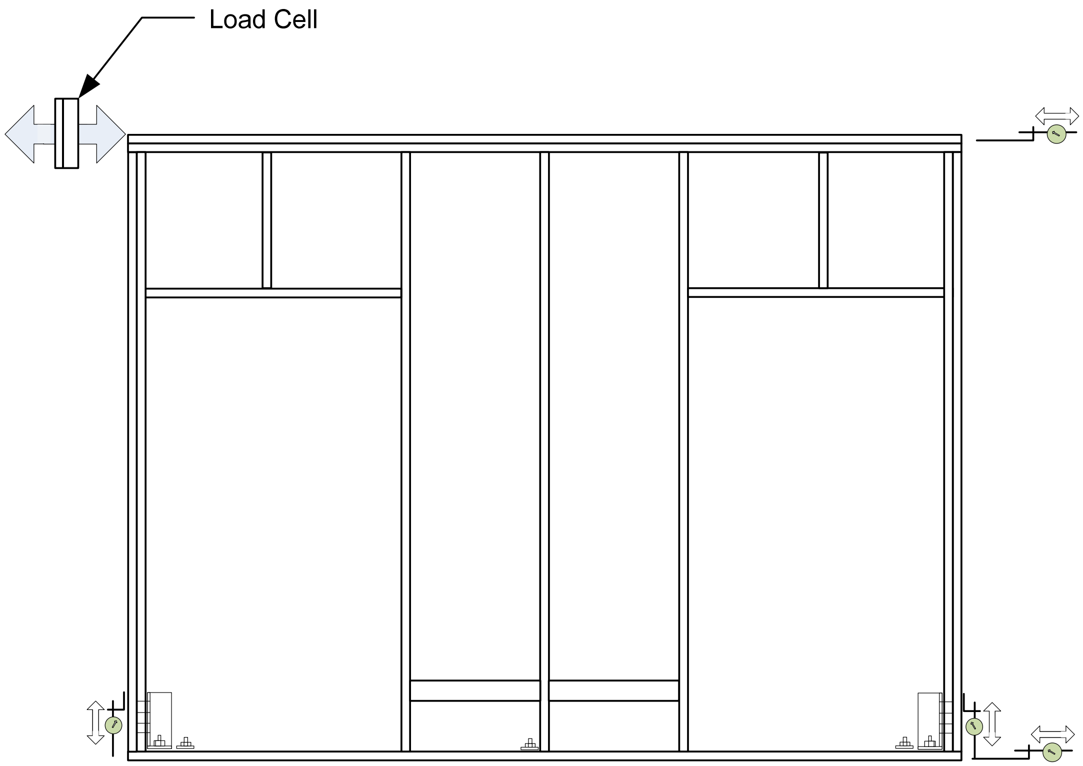
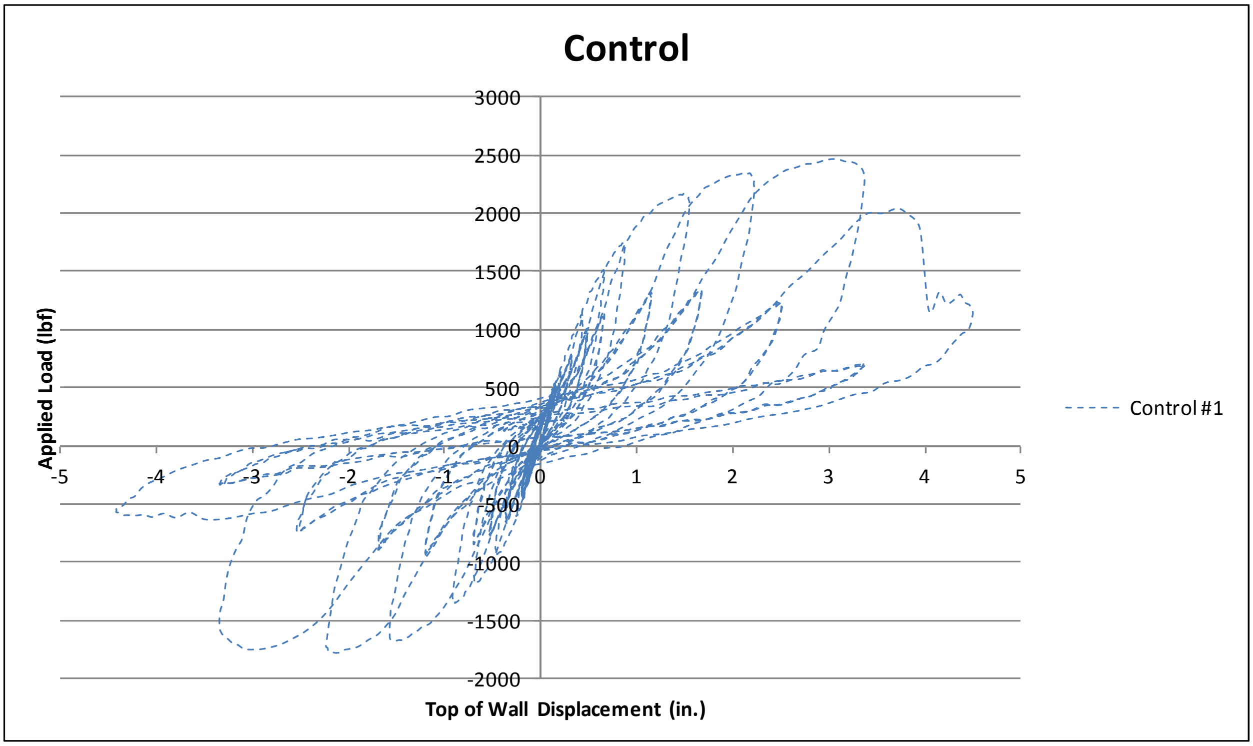
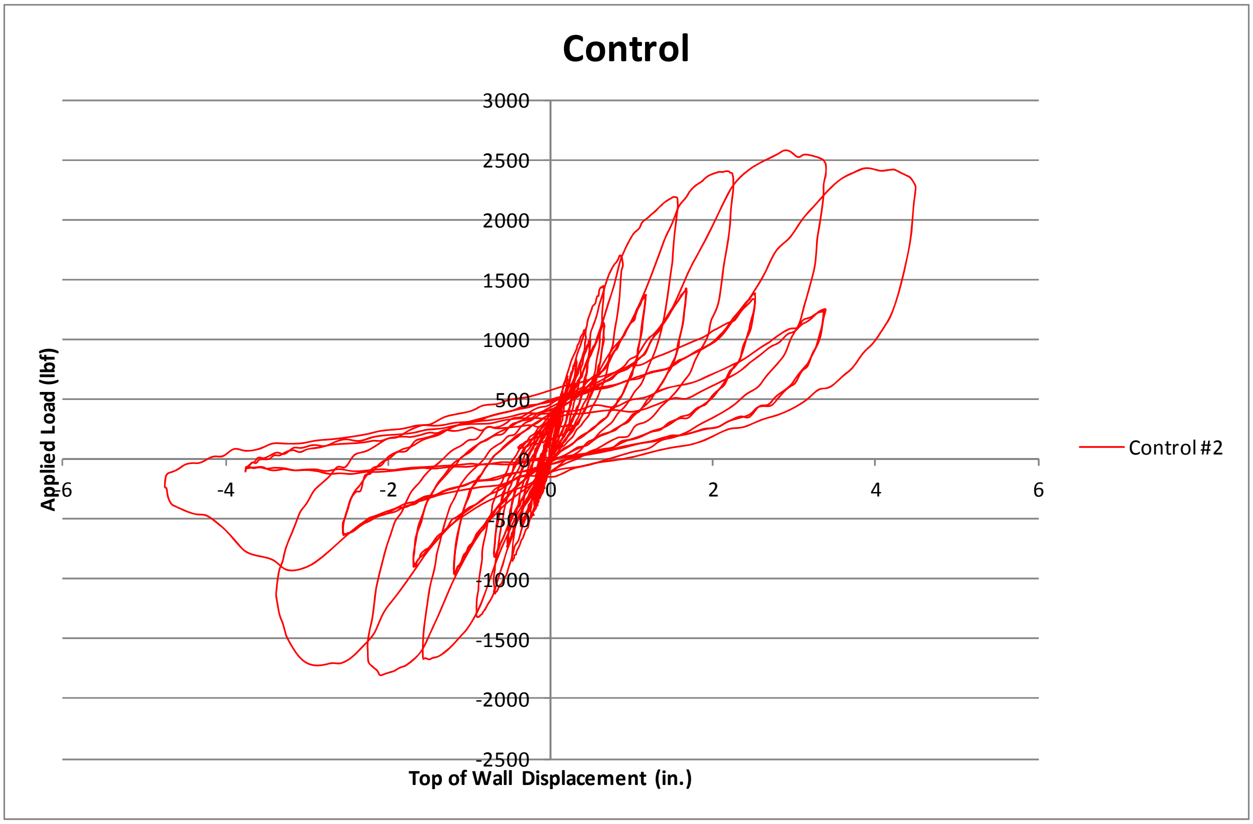



**Figure 15. Instrumentation (Typical).**

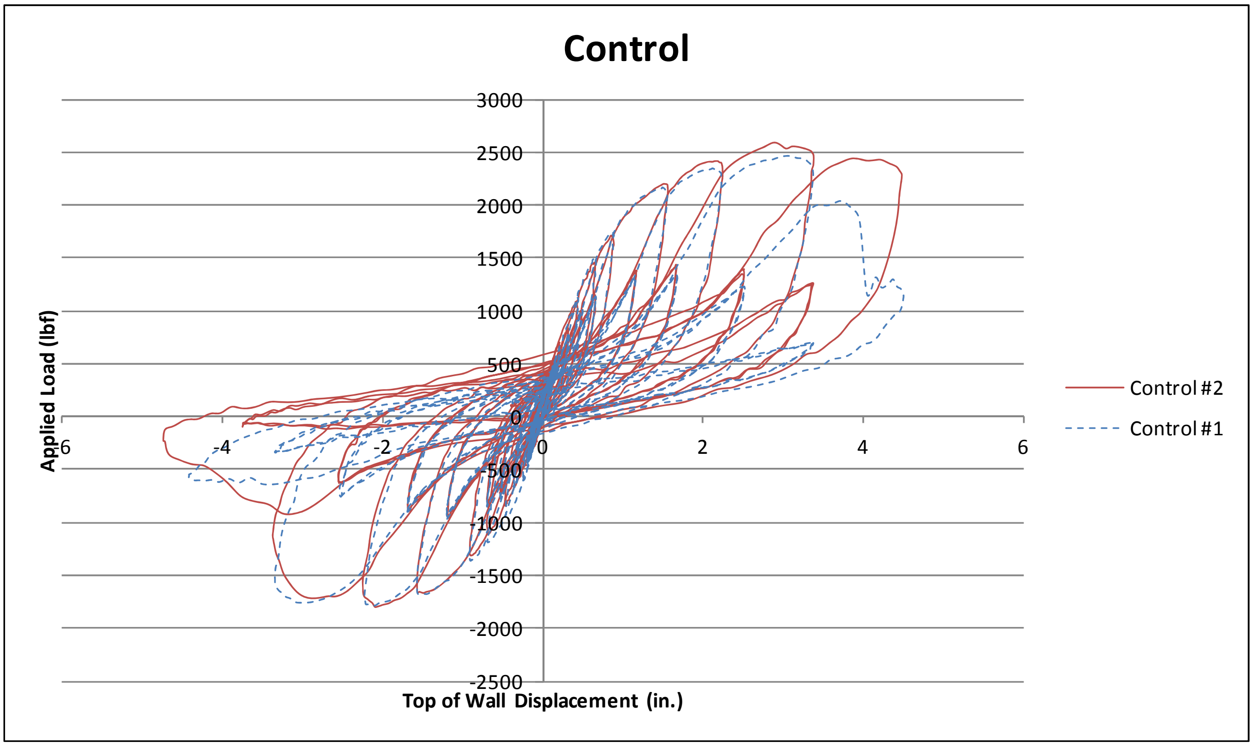
Appendix B: ASTM E2126 Test Plots (15 Pages)



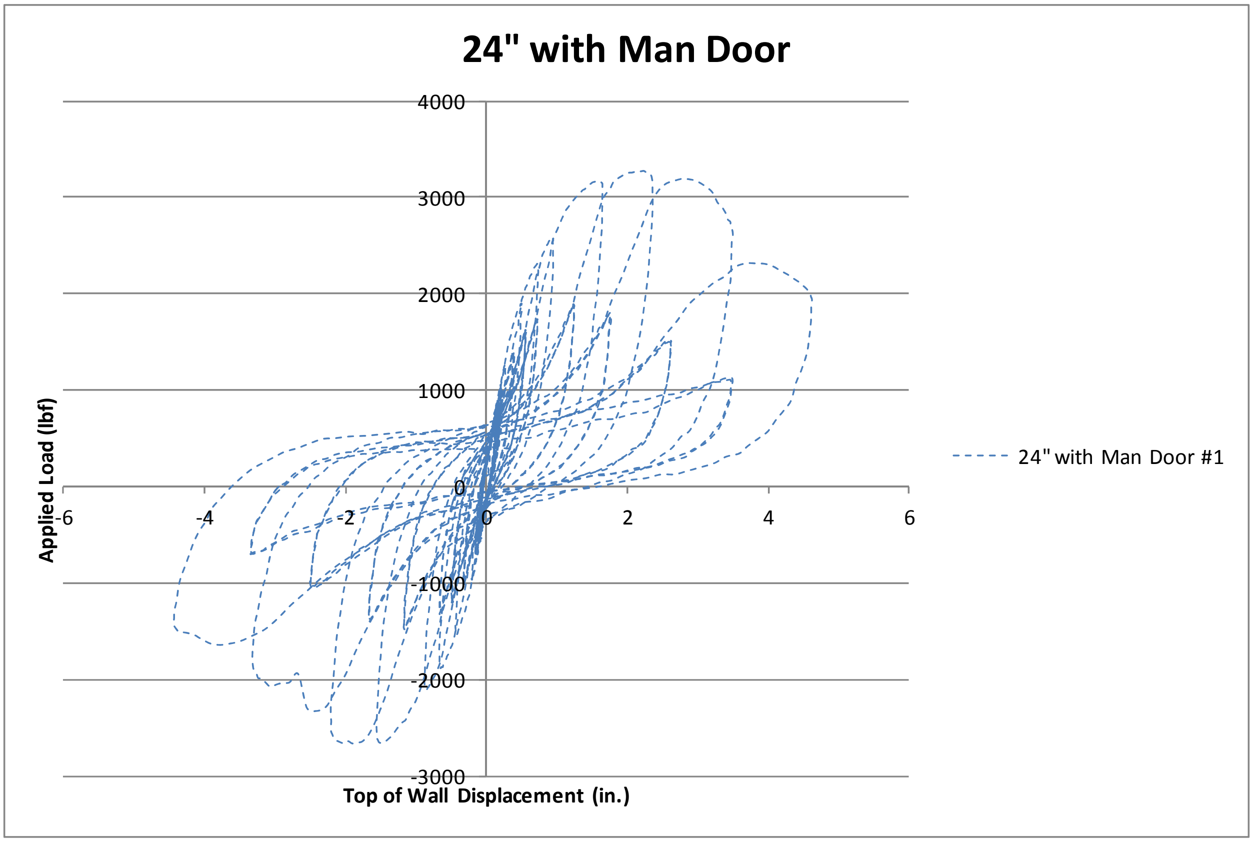

**Plot 1. Control Group Test Number 1 (C-1)**



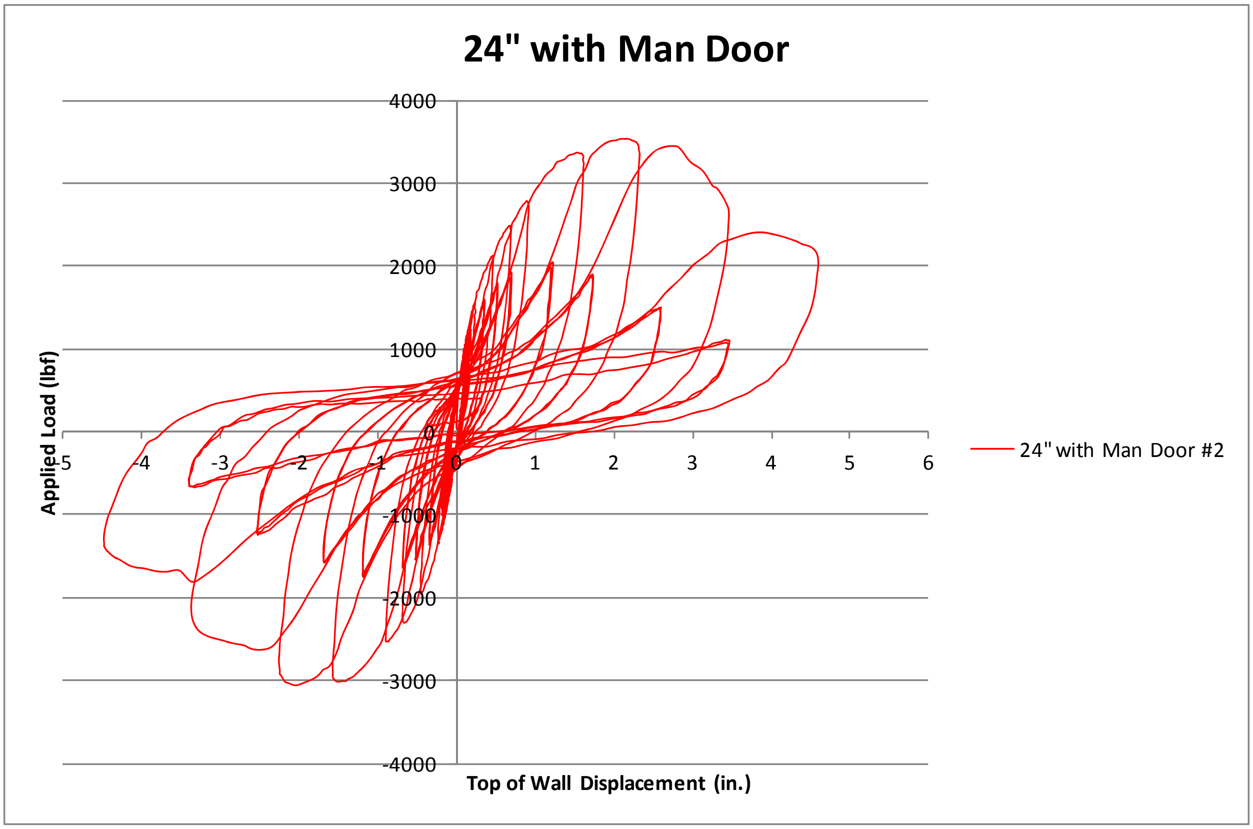

**Plot 2. Control Group Test Number 2 (C-2)**



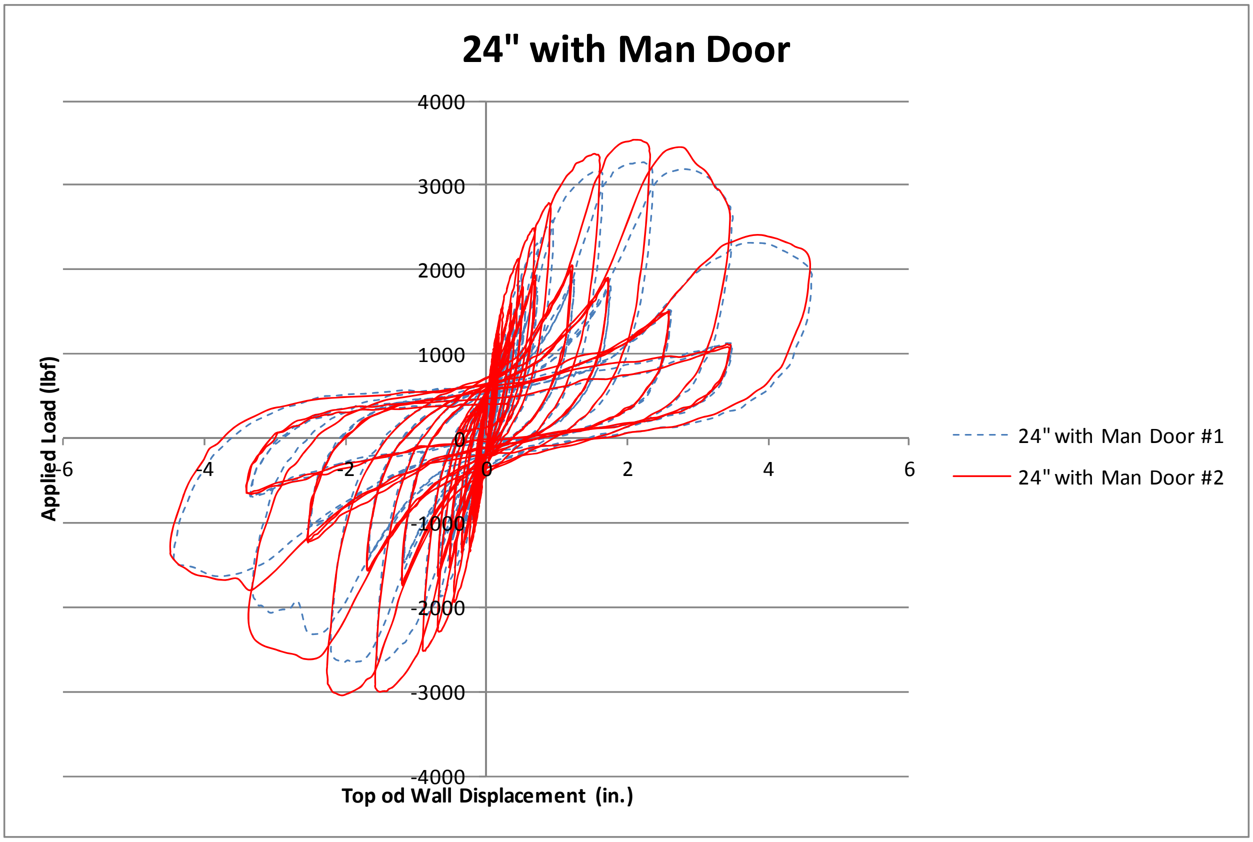

**Plot 3. Control Group Test Numbers 1 & 2 (C-1 & C-2)**



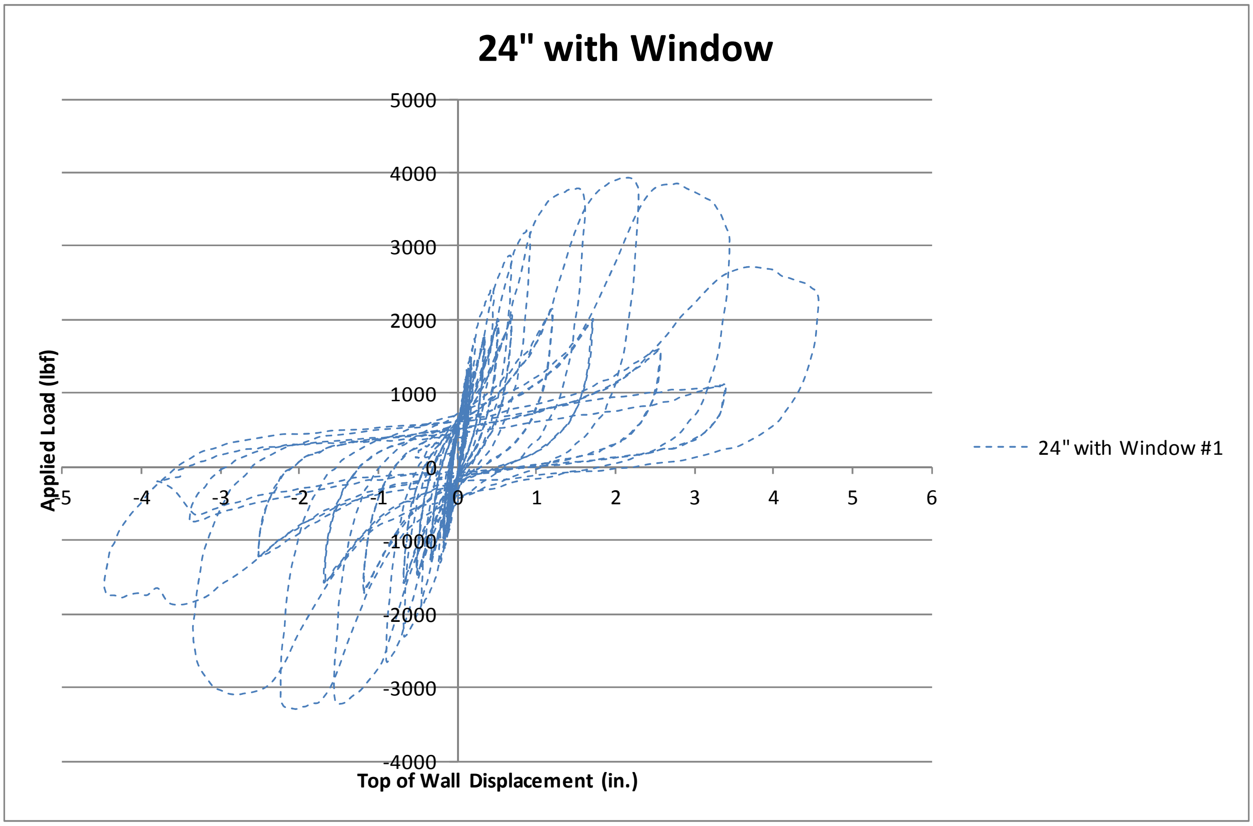

**Plot 4. 24″ Element with Man-Door Test Number 1 (1A-1)**



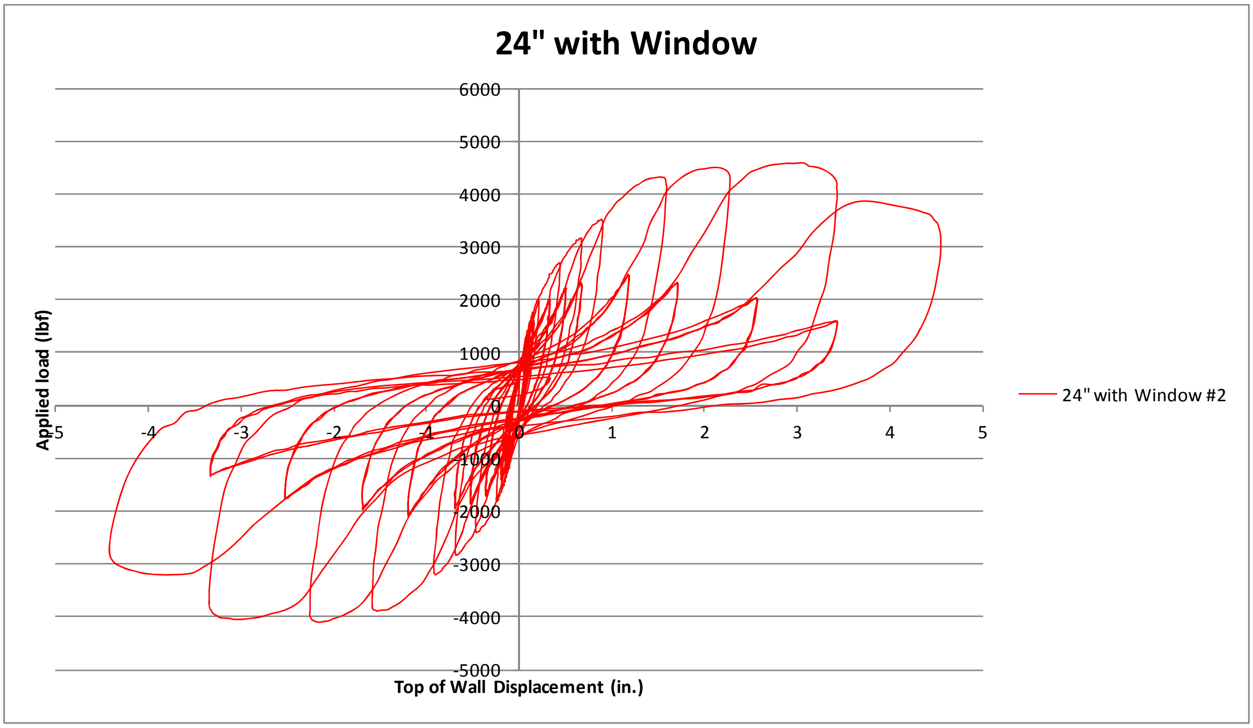

**Plot 5. 24″ Element with Man-Door Test Number 2 (1A-2)**



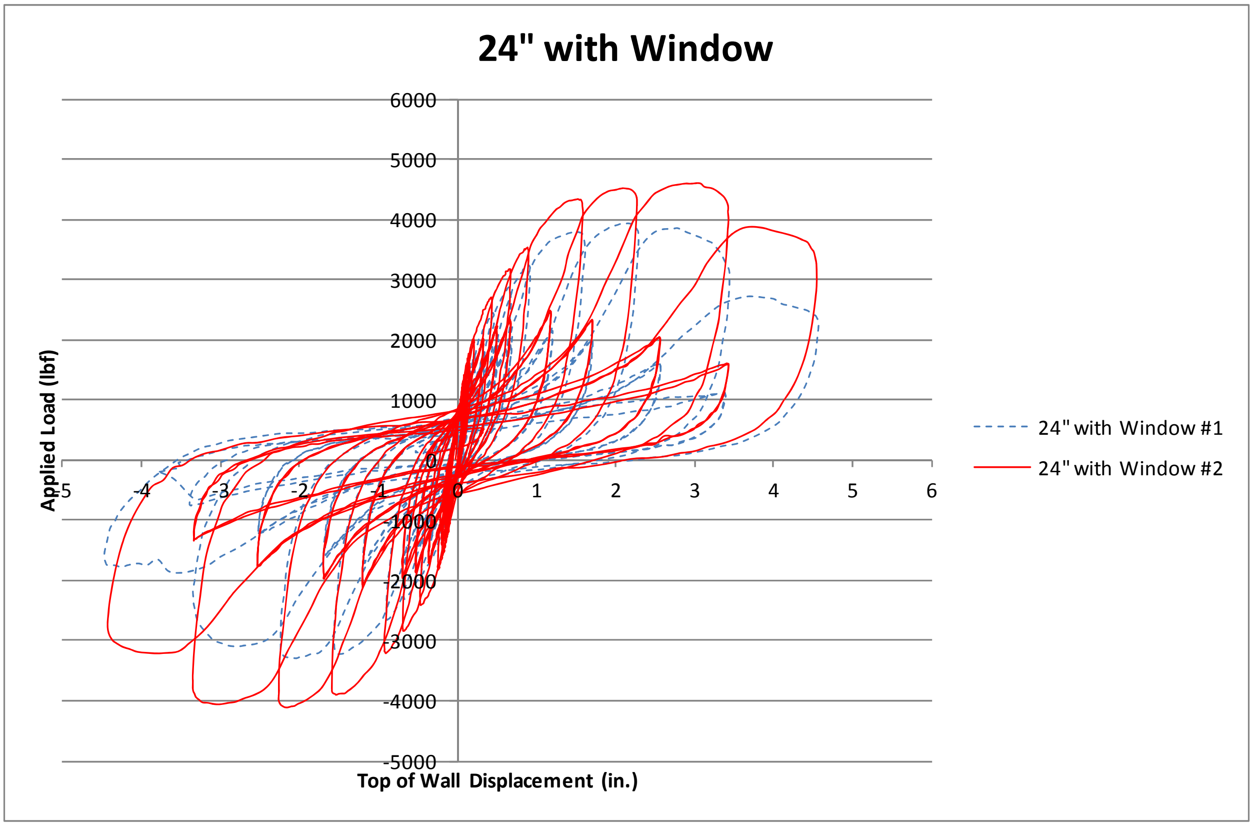

**Plot 6. 24″ Element with Man-Door Test Numbers 1 & 2 (1A-1 & 1A-2)**



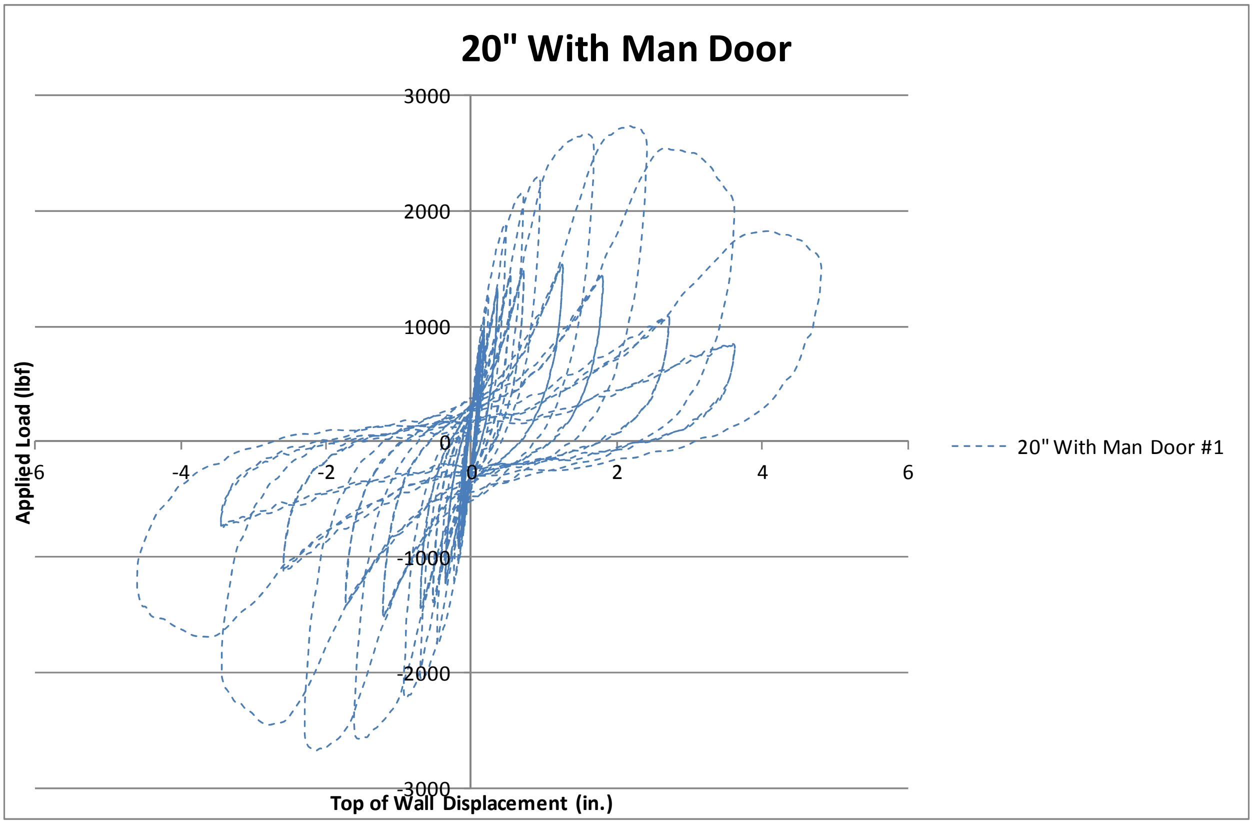

**Plot 7. 24″ Element with Window Test Number 1 (2A-1)**



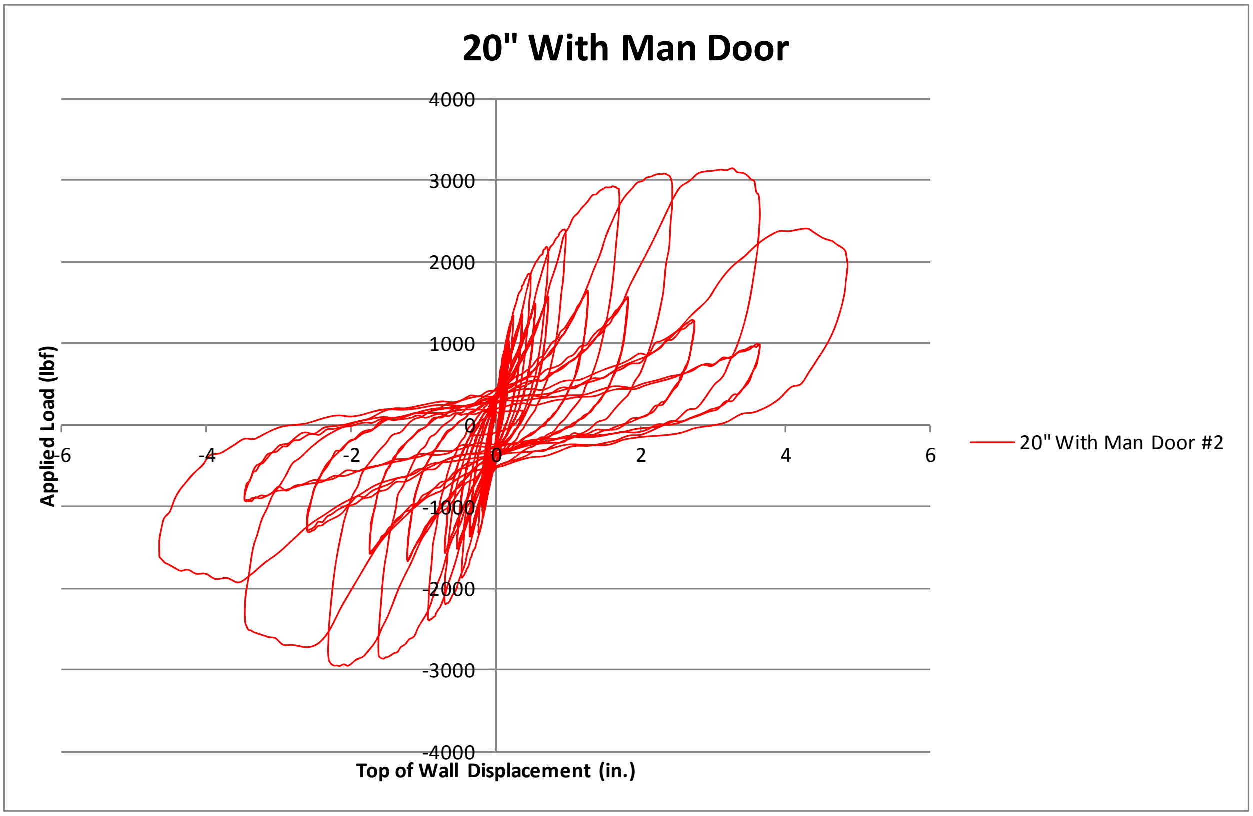

**Plot 8. 24″ Element with Window Test Number 2 (2A-2)**



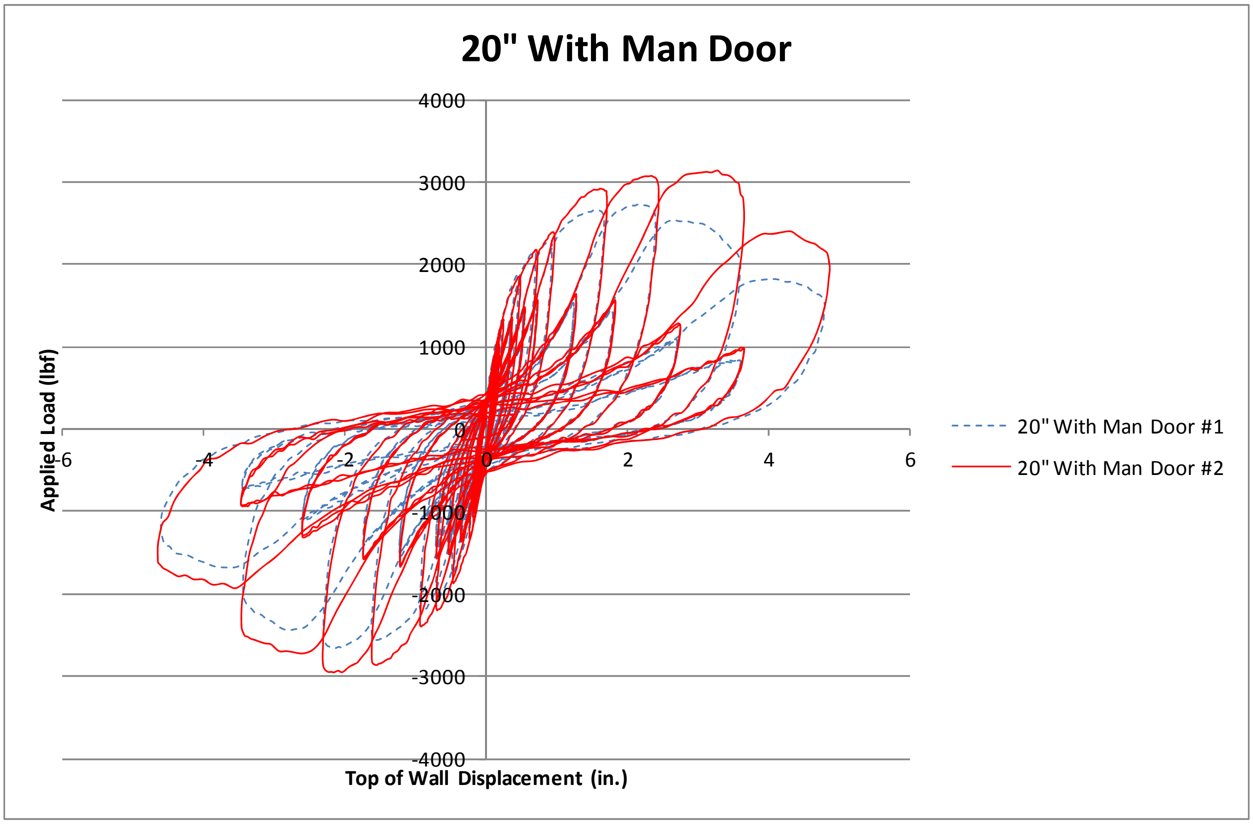

**Plot 9. 24″ Element with Window Test Numbers 1 & 2 (2A-1 & 2A-2)**



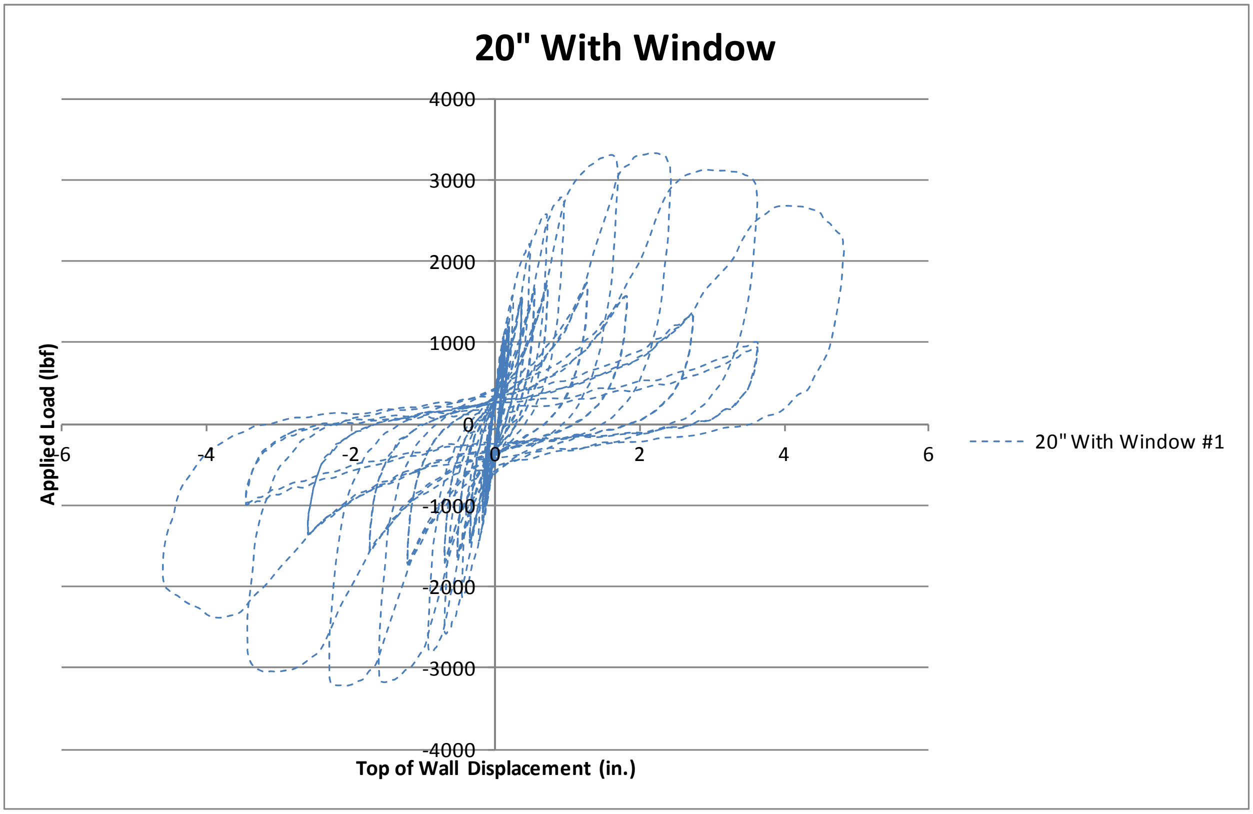

**Plot 10. 20″ Element with Man-Door Test Number 1 (1B-1)**




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

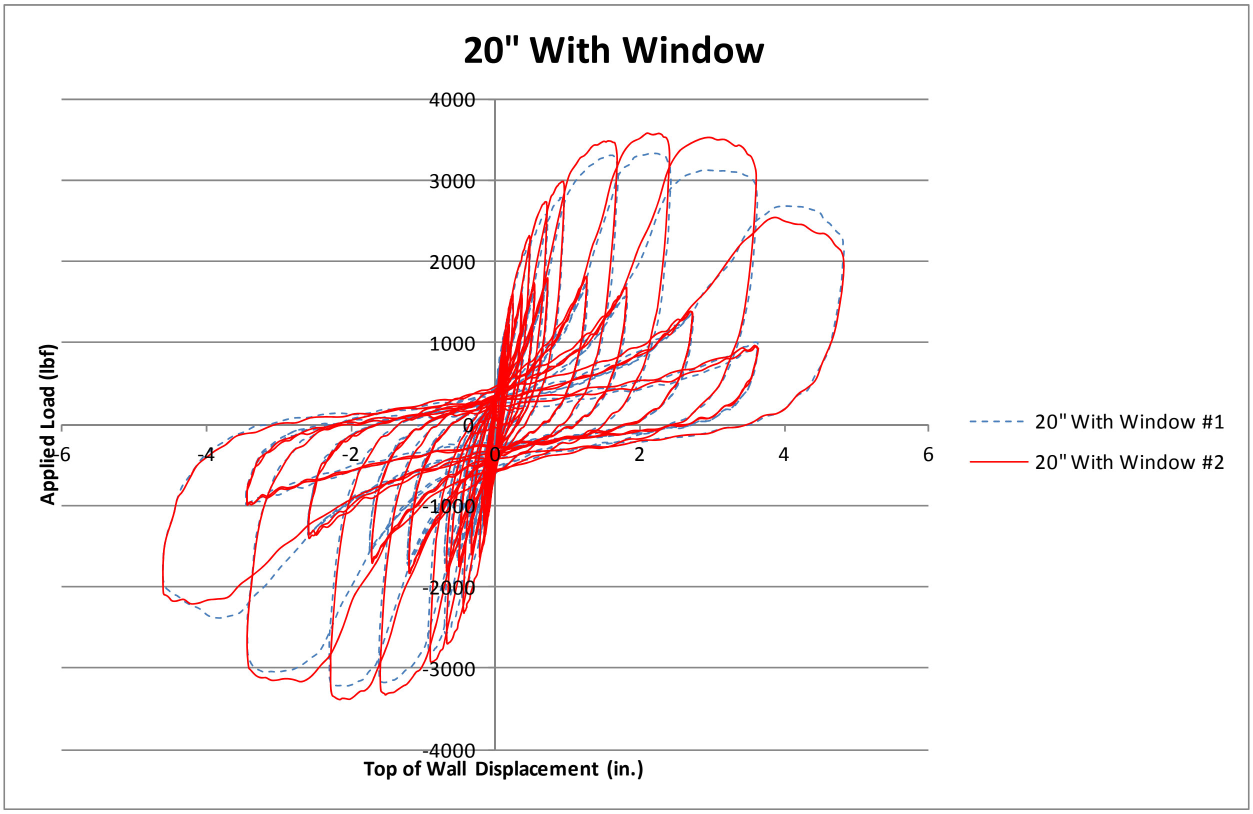



**Plot 12. 20″ Element with Man-Door Test Numbers 1 & 2 (1B-1 & 1B-2)**




**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)**