JOINT RESEARCH REPORT

Evaluation of Force Transfer Around Openings – Experimental and Analytical Studies

Effective Date March 21,2011

Final Report

USDA Joint Venture Agreement 09-11111133-117

APA

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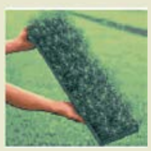

- *Life Cycle Assessment shows wood is the greenest building product.* A 2004 Consortium for Research on Renewable Industrial Materials (CORRIM) study gave scientific validation to the strength of wood as a green building product. In examining building products' life cycles - from extraction of the raw material to demolition of the building at the end of its long lifespan - CORRIM found that wood was better for the environment than steel or concrete in terms of embodied energy, global warming potential, air emissions, water emissions and solid waste production. For the complete details of the report, visit www.CORRIM.org.

- **Manufacturing wood is energy efficient.** Wood products made up 47 percent of all industrial raw materials manufactured in the United States, yet consumed only 4 percent of the energy needed to manufacture all industrial raw materials, according to a 1987 study

Material	Percent of Production	Percent of Energy Use
Wood	47	4
Steel	23	48
Aluminum	2	8

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EVALUATION OF FORCE TRANSFER AROUND OPENINGS – EXPERIMENTAL AND ANALYTICAL STUDIES

Final Report
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EXECUTIVE SUMMARY

This report contains research results on one of the major design methods concerning wood structural panel (WSP) sheathed shear walls with openings – force transfer around openings (FTAO). This study was undertaken by a joint effort between APA – *The Engineered Wood Association and the* USDA Forest Products Laboratory (FPL), Madison, WI under a joint venture agreement funded by both organizations. The University of British Columbia, Vancouver, BC, provided technical supports and consultation on the computer shear wall model simulation and analysis.

The design method for force transfer around openings has been the subject of interest by some engineering groups in the U.S., such as the Structural Engineers Association of California (SEAOC). Excellent examples of FTAO targeted to practitioners have been developed by a number of sources. However, very little test data are available to confirm design assumptions. Among various techniques that are generally accepted as a rational analysis in practice, drag strut, cantilever beam and Diekmann technique were examined in this study and a wide range of predicted forces was noted. This variation in predicted forces results in some structures being either over-built or less reliable than the intended performance objective.

This research was performed in two parts. Part 1 was an experimental study conducted at APA and Part 2 was a model analysis performed by the UBC based on the experimental study plan from Part 1. This report is presented based on these two approaches. This is the first of a series of studies that are designed to look into this design method in hope for a better characterization and understanding of the method.

This research was supported in part by funds provided by the USDA Forest Products Laboratory, which is acknowledged and greatly appreciated by the project team.

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PART 1: FULL-SCALE SHEAR WALL TESTS FOR FORCE TRANSFER AROUND OPENINGS

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ABSTRACT

Wood structural panel (WSP) sheathed shear walls and diaphragms are the primary lateral-load-resisting elements in wood-frame construction. The historical performance of light-frame structures in North America is very good due, in part, to model building codes that are designed to safeguard life safety. These model building codes have spawned continual improvement and refinement of engineering solutions. There is also an inherent redundancy of wood-frame construction using WSP shear walls and diaphragms. As wood-frame construction is continuously evolving, designers in many parts of North America are optimizing design solutions that require the understanding of force transfer between lateral load-resisting elements.

The North American building codes provide three solutions to walls with openings. The first solution is to ignore the contribution of the wall segments above and below openings and only consider the full-height segments in resisting lateral forces, often referred to as segmented shear wall method. The second approach, which is to account for the effects of openings in the walls using an empirical reduction factor, is known as the “perforated shear wall method.” The final method, which has a long history of practical use, is the “force transfer around openings method.” This method is codified and accepted as simply following “rational analysis.” Much engineering consideration has been given to this topic (SEAOSC Seismology Committee, 2007) and excellent examples targeted to practitioners have been developed by a number of sources (SEAOC, 2002, Breyer et al. 2007, Diekmann, 1998). However, unlike the perforated shear wall method, very little test data has been collected to verify various rational analyses. Typically walls that are designed for force transfer around openings attempt to reinforce the wall with openings such that the wall performs as if there was no opening. Generally increased nailing in the vertical and the horizontal directions as well as blocking and strapping are common methods being utilized for this reinforcement around openings. The authors are aware of at least three techniques which are generally accepted as rational analysis. For this paper, drag strut, cantilever beam and Diekmann technique were used to predict force transfer around openings. These techniques result in wide ranges of predicted forces. This variation in predicted forces results in some structures being either over-built or less reliable than the intended performance objective.

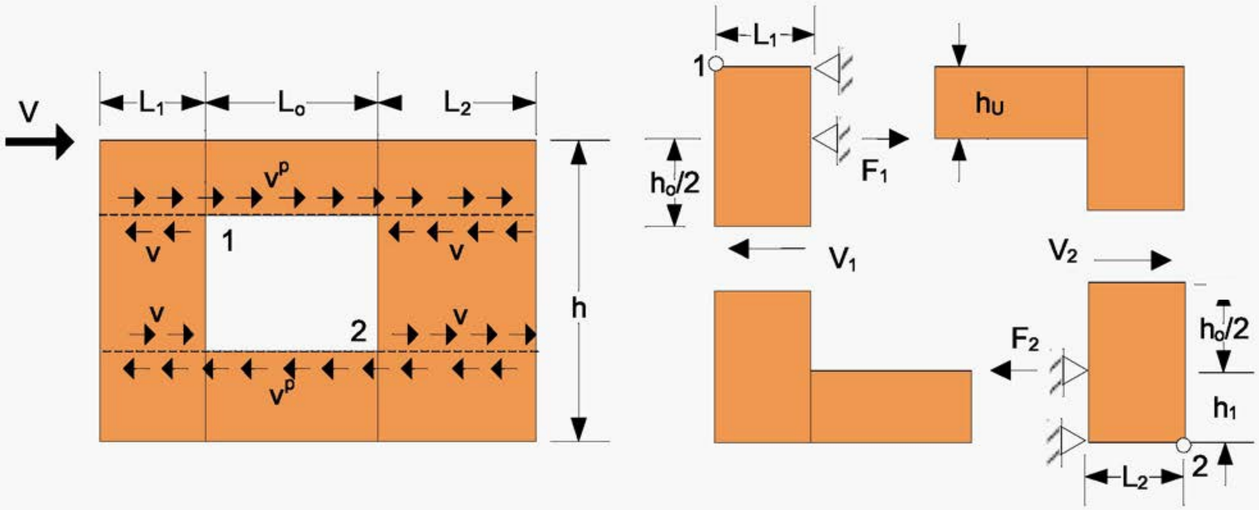
A joint research project of APA – The Engineered Wood Association, the University of British Columbia (UBC), and the USDA Forest Products Laboratory (FPL) was initiated in 2009 to evaluate the variations of walls with pier widths that meet code prescribed limitations. This study examines the internal forces generated during these tests and evaluates the effects of size of openings, location of openings, size of full-height piers, and different construction techniques by using the segmented method, the perforated shear wall method, and the force transfer around openings method. Full-scale wall tests as well as analytical modeling were performed. The research results obtained from this study will be used to support design methodologies in estimating the forces around the openings. This report provides test results from 8 feet x 12 feet full-scale wall configurations, which will be used in conjunction with the analytical results from a computer model developed by the UBC to develop rational design methodologies for consideration by the U.S. design codes and standards.

1.1 INTRODUCTION

The North American building codes provide three solutions to walls with openings. The first solution is to ignore the contribution of the wall segments above and below openings and only consider the full-height segments in resisting lateral forces, often referred to as segmented shear wall method. This method could be considered the traditional shear wall method. The second approach, which is to account for the effects of openings in the walls using an empirical reduction factor, is known as the "perforated shear wall method." This method has tabulated empirical reduction factors and a number of limitations on the method. In addition, there are a number of special detailing requirements that are not required by the other two methods. The final method is codified and accepted as simply following "rational analysis." Much engineering consideration has been given to this topic (SEAOSC Seismology Committee, 2007) and excellent examples targeted to practitioners have been developed by a number of sources (SEAOC, 2002, Breyer et al. 2007, Diekmann, 1998). However, unlike the perforated shear wall method, very little test data has been collected to verify various rational analyses. Typically walls that are designed for force transfer around openings attempt to reinforce the wall with openings such that the wall performs as if there was no opening. Generally increased nailing in the vertical and the horizontal directions as well as blocking and strapping are common methods being utilized for this reinforcement around openings. The authors are aware of at least three techniques which are generally accepted as rational analysis. The "drag strut" technique is a relatively simple rational analysis which treats the segments above and below the openings as "drag struts" (Martin, 2005). This analogy assumes that the shear loads in the full-height segments are collected and concentrated into the sheathed segments above and below the openings. The second simple technique is referred to as "cantileverbeam." This technique treats the forces above and below the openings as moment couples, which are sensitive to the height of the sheathed area above and below the openings. A graphical representation of these two techniques is given in Figure 1. The mathematical development of these two techniques is presented by Martin (2005).

FIGURE 1

REPRESENTATION OF THE DRAG STRUT TECHNIQUE (LEFT) AND THE CANTILEVER BEAM TECHNIQUE (RIGHT) FOR ESTIMATING FORCES AROUND WALL OPENINGS (MARTIN. 2005)

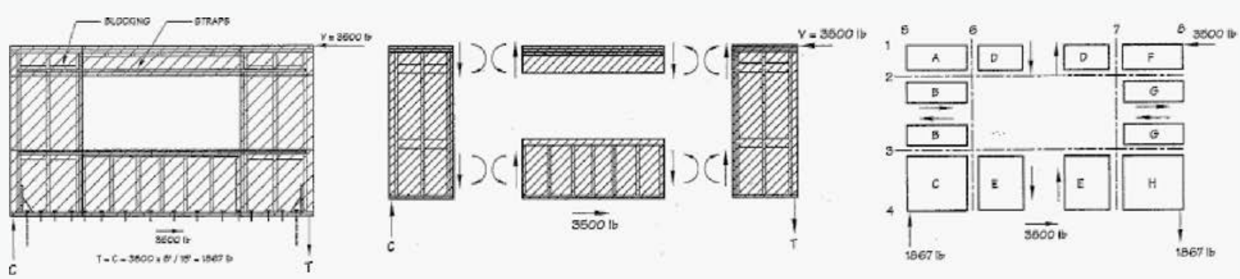


Finally, the more rigorous mathematical technique is typically credited to a California structural engineer, Edward Diekmann, and well documented in the wood design textbook by Breyer et al. (2007). This technique assumes that the wall behaves as a monolith and internal forces are resolved by creating a series of free body diagrams as illustrated in Figure 2. This is a common technique used by many west coast engineers in North America. Although the technique can be tedious for realistic walls with multiple openings, many design offices have developed spreadsheets based on either the Diekmann method or SEAOC (2002). A known limitation of this technique is that when the height above opening is less than 12 inches, the resolved shear forces become quite large, resulting in the apparent overstressing of the wood structural panel wall sheathing.

Of the three common techniques, the predicted internal forces can vary significantly, based on wall geometry. In extreme cases discussed below, the differences in the predicted internal forces may vary by 800%. The purpose of this research is to provide experimental data for comparison and perhaps improvement to the rational analyses.

FIGURE 2

REPRESENTATION OF THE DIEKMANN TECHNIQUE (1998) AND DRAWINGS FROM BREYER ET AL. (2007). Global free body diaphragm of wall with openings (left), beam behaviour of various sheathed areas (center), and horizontal and vertical cuts for establishing internal shears (right)



1.2 TEST PLAN

In an effort to collect internal forces around openings of loaded walls, a series of twelve wall configurations were tested, as shown in Figure 3. The left hand side of Figure 3 illustrates a framing plan, which also includes anchor bolt and holddown location and additional details. On the right hand side of Figure 3, sheathing and strapping plan is illustrated. This test series is based on the North American code permitted walls nailed with 10d common nails (0.148 inches by 3 inches) at a nail spacing of 2 inches. The sheathing used in all cases was nominal 15/32-inch oriented strand board (OSB) APA STR I Rated Sheathing. All walls were 12 feet long and 8 feet tall. The lumber used for all of these tests was kiln-dried Douglas-fir, purchased from the open market, and was tested after conditioned to indoor laboratory environments (i.e. dry conditions). Each individual 2x4 stud was nailed to the respective end plates with two 16d common (0.162 inch by 3-1/2 inch) end nails. The headers were built-up double 2x12s with a 1/2-inch wood structural panel spacer between the two pieces of lumber. In general, built-up 2x members were face-nailed to each other with 10d common nails face-nailed at 8 inches on center.

The walls were attached to the steel test jig with 5/8-inch diameter anchor bolts with 3x3x0.229-inch square plate washers. In some cases, 5/8-inch Strainsert calibrated bolts were substituted for the anchor bolts such that uplift forces at the anchor bolts could be directly measured. Figure 3 illustrates anchor bolt location and where the calibrated bolts were located. The overturning of the walls was resisted by Simpson Strong-Tie HDQ8 Hold-downs, attached to the double 2x4 end studs with 20 - 1/4-x3-inch SDS screws. These hold-downs were attached to the steel test jig with 7/8-inch diameter bolts. In some cases, 7/8-inch calibrated bolts were substituted for the hold-down bolts such that hold-down forces could be directly measured.

Wall 1 is based on the narrowest segmented wall (height-to-width ratio of 3.5:1) permitted by the code with overturning restraint (hold-downs) on each end of the full-height segments. Simpson Strong-Tie HDQ8 hold-downs were used to resist the overturning restraint for the twelve wall configurations. The height of the window opening for Wall 1 is common to many walls tested in this plan, at 3 feet. Walls 2 and 3 are based on the perforated shear wall method,

C_0 = 0.93. Hold-downs are located on the ends of the wall with no special detailing other than the compression blocking on Wall 3. Wall 4 is a force transfer around openings wall which has identical geometry to Walls 1, 2 and 3, and is used to compare the various methods for designing walls with openings.

Wall 5 has the same width of piers as the first four walls. However, the opening height was increased to 5 feet. Wall 6 was common to Wall 4 with the exception that the typical 4 feet x 8 feet sheathing was "wrapped around the wall opening in "C" shaped pieces. This framing technique is commonly used in North America. It can be more time efficient to sheath over openings at first and then remove the sheathing in the openings area via a hand power saw or router.

Wall 7 is a segmented wall with height-to-width ratio of the full-height segments to 2:1. Wall 8 is a match to Wall 7, but designed as a force transfer around openings wall. The window height in Wall 9 is increased from 3 feet to 5 feet tall. Walls 10 and 11 contain very narrow wall segments for use in large openings such as garage fronts. The two walls are designed with openings on either side of pier and only on wall boundary, respectively. Finally, Wall 12 contains a wall with two asymmetric openings.

Most walls were tested with a cyclic loading protocol following ASTM E 2126, Method C, CUREE Basic Loading Protocol. The reference deformation, Δ, was set as 2.4 inches. The term a was 0.5, resulting in maximum displacements applied to the wall of +/- 4.8 inches. This displacement level was based on APA's past experience with cyclic testing of WSP shear walls. The displacement-based protocol was applied to the wall at 0.5 Hz with the exception of Wall 8b, which was loaded at 0.05 Hz. Two walls (Wall 4c and 5c) were tested following a monotonic test in accordance with ASTM E 564.

Several different top plate boundary conditions were used for this series of tests. Table 1 lists which load head was used for the various tests. The first load head used was deemed the "short" load head. The load head was fabricated from two commercial hold-downs, and attached to the top of the wall with a number of 1/4-inch diameter self-drilling, self-tapping lag screws. The intent was that the short load head would not provide additional stiffness to the double wood top plate of the wall. The racking loads were transferred into the first full-height pier, and the load head did not extend to the header. However, as wall forces became larger, the load head resulted in a large concentrated force at the end of the load head. Figure F1 shows a double top plate net section fracture, as related to the short load head.

An intermediate load head was also utilized in some of the tests. The intermediate load head was a longer channel that was built up by welding two angles, toe-to-toe, together. The load head was directly connected to the top of the wall with a number of 1/4-inch diameter self-drilling, self-tapping lag screws. This load head provided very little additional stiffness to the double top plate of the wall. However, the length of the load head did not extend the entire length of the 12-foot-long walls, thus providing different top plate boundary conditions over the two full-height piers. There was also some concern that the internal forces on one end of the wall were being transferred through the load head, and not through the straps. Figure F2 shows this load head.

A special cyclic "long" load head was fabricated that extended the entire length of the wall. This load head "floated over the wall, making no direct continuous contact to the top of the wall, thus assuring all force continuity on the walls intended for studying force transfer around openings was achieved via the straps. The racking forces were transferred directly into the double top plates by end-grain bearing, for both the "push" and the "pull" cycle. Large diameter bolts were installed in slotted holes (slots parallel to length of wall) into the full-height piers. The purpose of these bolts and slotted holes was to eliminate racking forces from being transferred through the bolts, while providing restraints that forced the wall to remain planar. Figure F3 shows this load head.

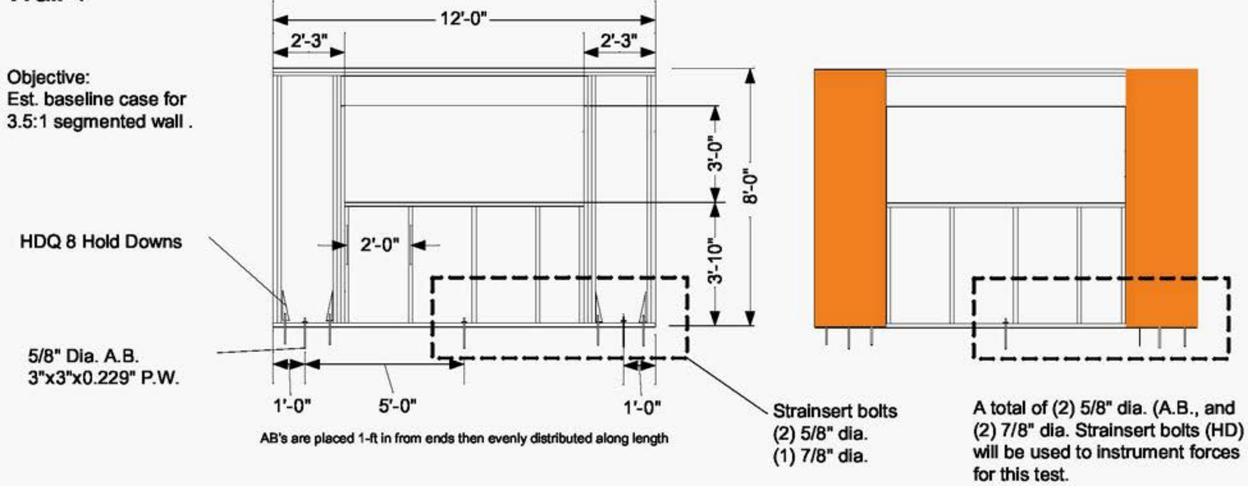
Finally, monotonic racking tests were conducted with the load being transferred directly into the top plate; thus no load head was utilized. The wall remained planar via structural tubes and low friction rub blocks directly bearing on face and back side of wall. Figure F4 shows this setup.

For walls detailed as force transfer around openings, two Simpson Strong-Tie HTT22 hold-downs in line (facing seat-to-seat) were fastened through the sheathing and into the flat blocking (Wall 4 in Figure 3, Figure 5, and Figure F12 in Appendix F illustrate this detail). The hold-downs were intended to provide similar force transfer as the typically detailed flat strapping around openings. The hold-downs were connected via a 5/8-inch diameter calibrated tension bolt for measuring tension forces.

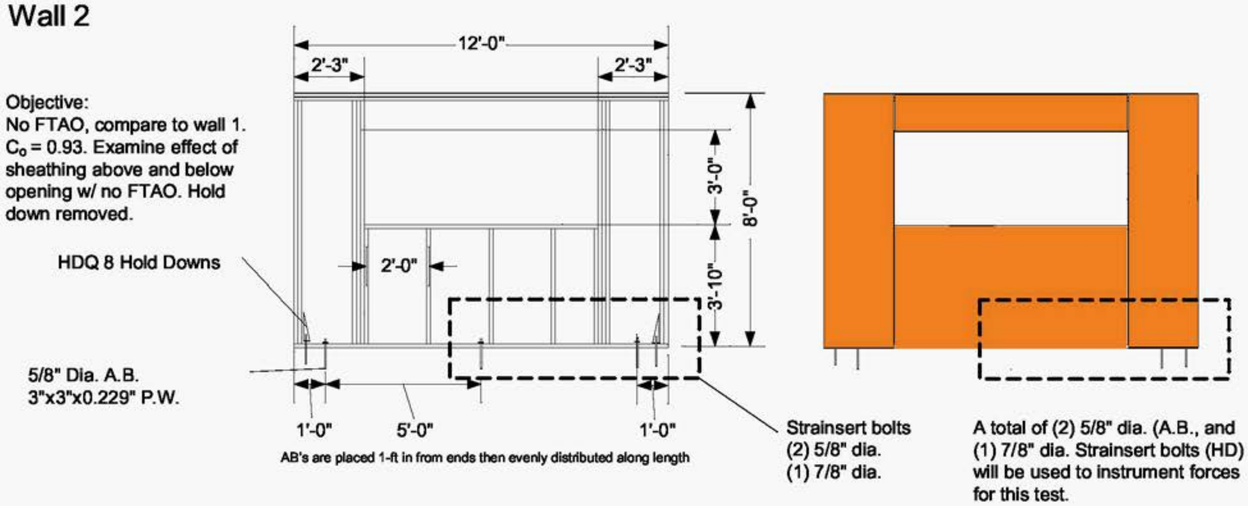
FIGURE 3

FRAMING PLANS (RIGHT) AND SHEATHING PLANS (LEFT) FOR VARIOUS FORCE TRANSFER AROUND OPENINGS ASSEMBLIES

Wall 1



Wall 2



Wall 3

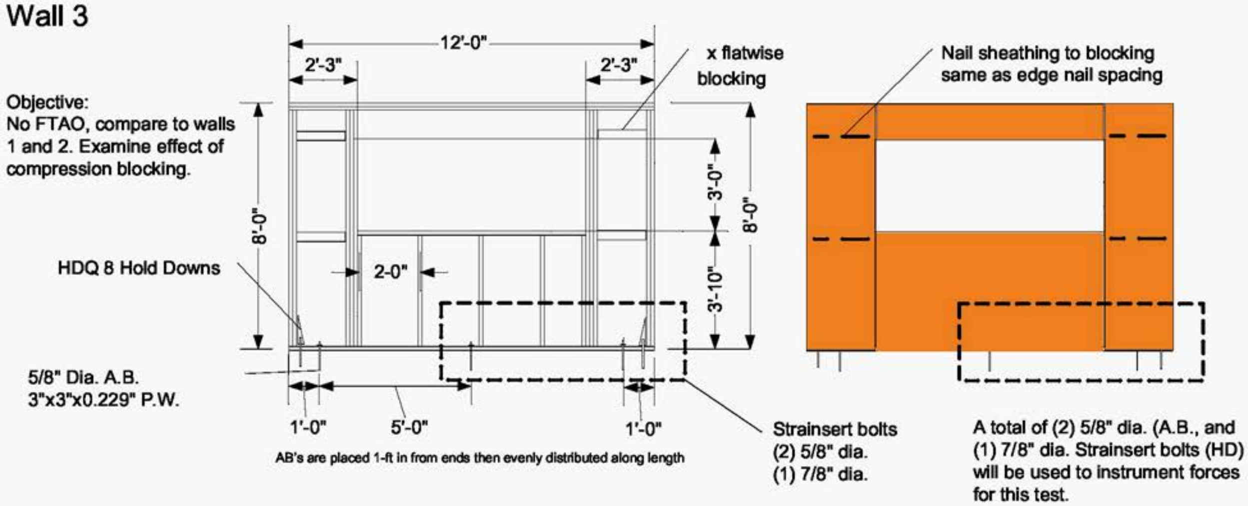
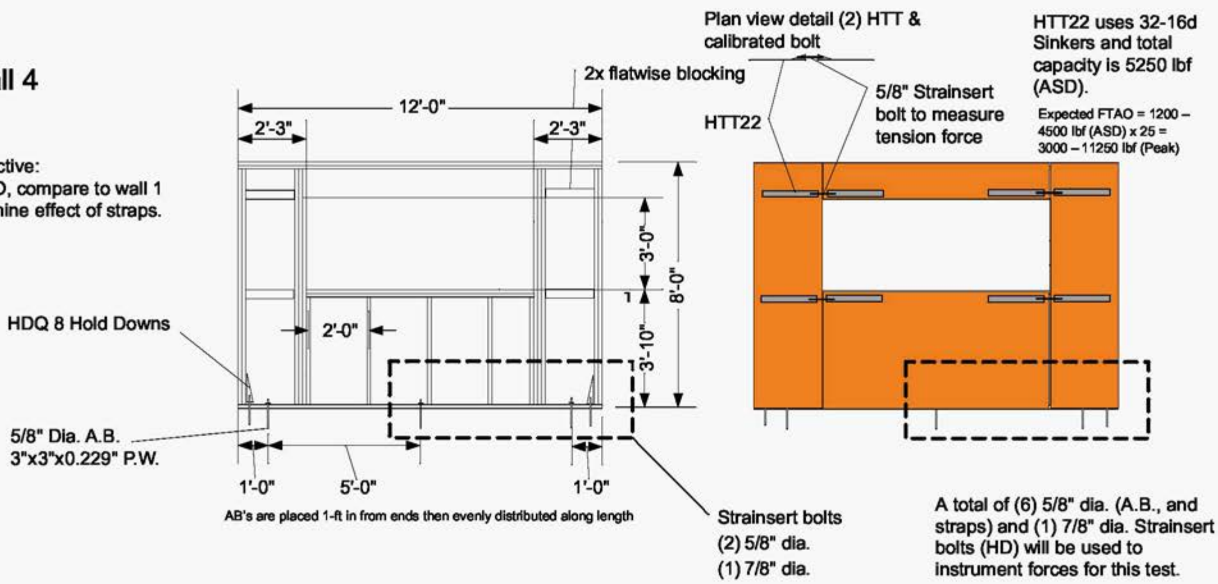


FIGURE 3 (Continued)

FRAMING PLANS (RIGHT) AND SHEATHING PLANS (LEFT) FOR VARIOUS FORCE TRANSFER AROUND OPENINGS ASSEMBLIES

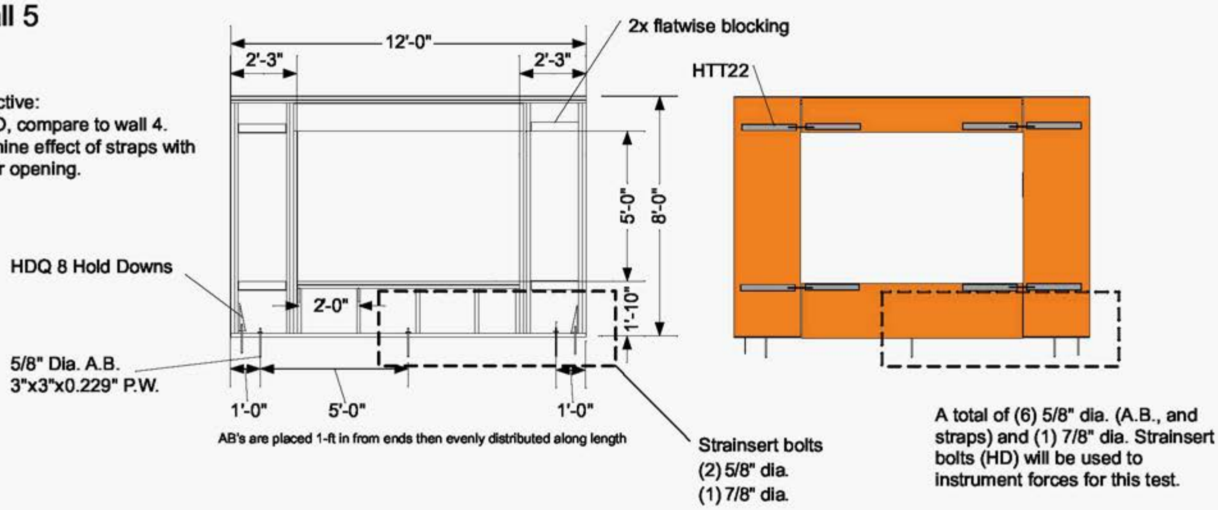
Wall 4

Objective:
FTAO, compare to wall 1
Examine effect of straps.



Wall 5

Objective:
FTAO, compare to wall 4.
Examine effect of straps with larger opening.



Wall 6

Objective:
Compare to wall 4. Examine effect of sheathing around opening.

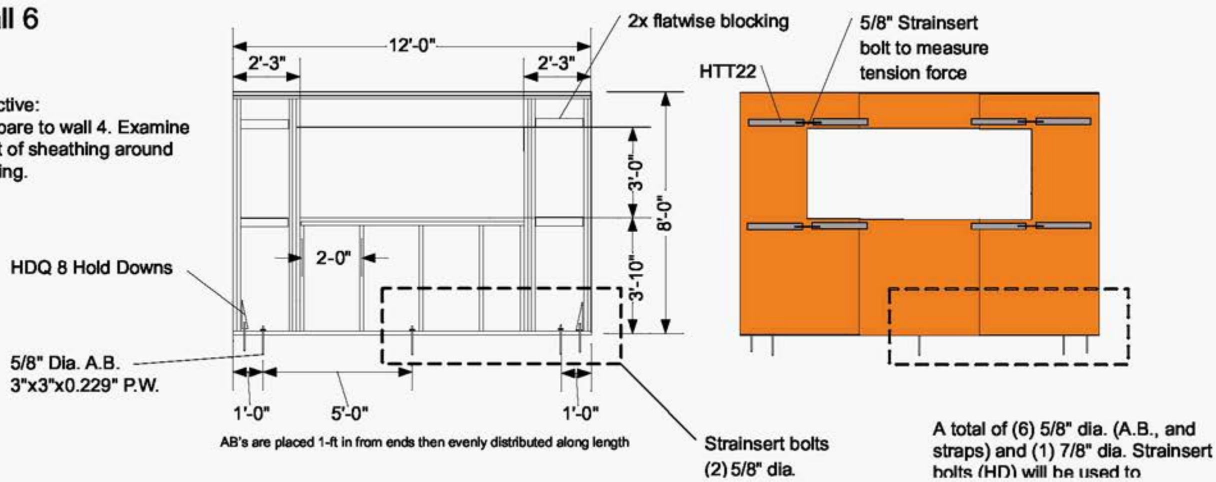
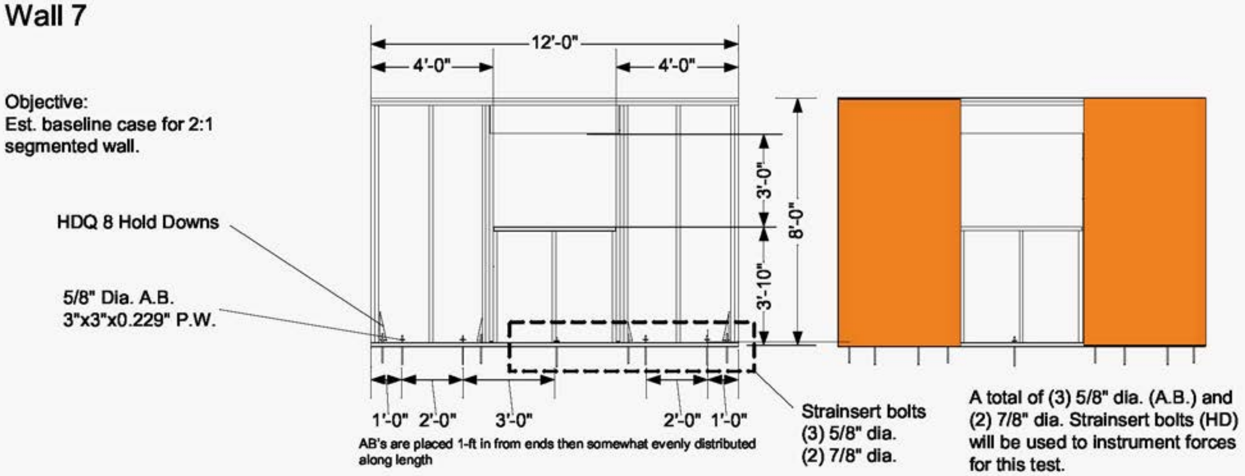


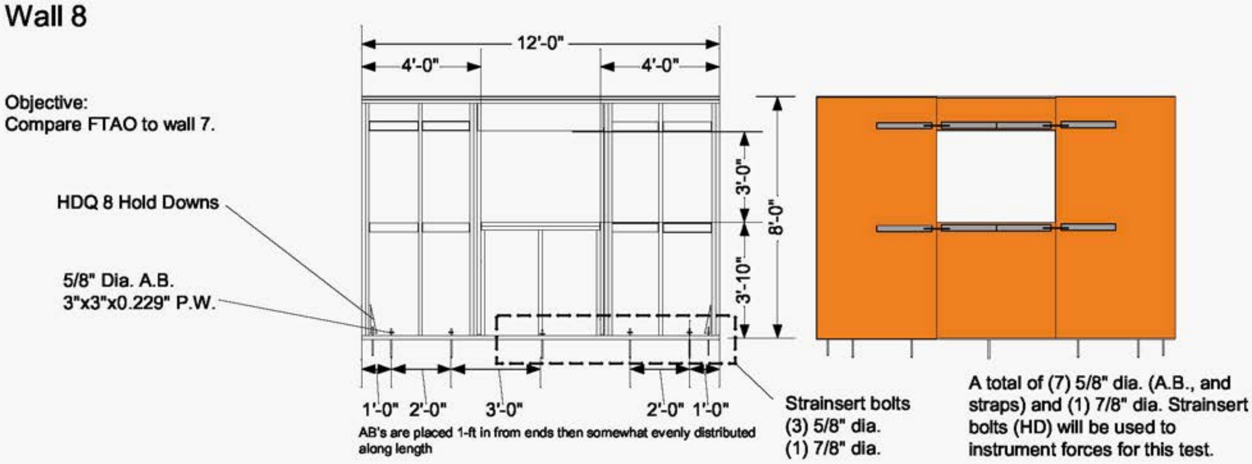
FIGURE 3 (Continued)

FRAMING PLANS (RIGHT) AND SHEATHING PLANS (LEFT) FOR VARIOUS FORCE TRANSFER AROUND OPENINGS ASSEMBLIES

Wall 7



Wall 8



Wall 9

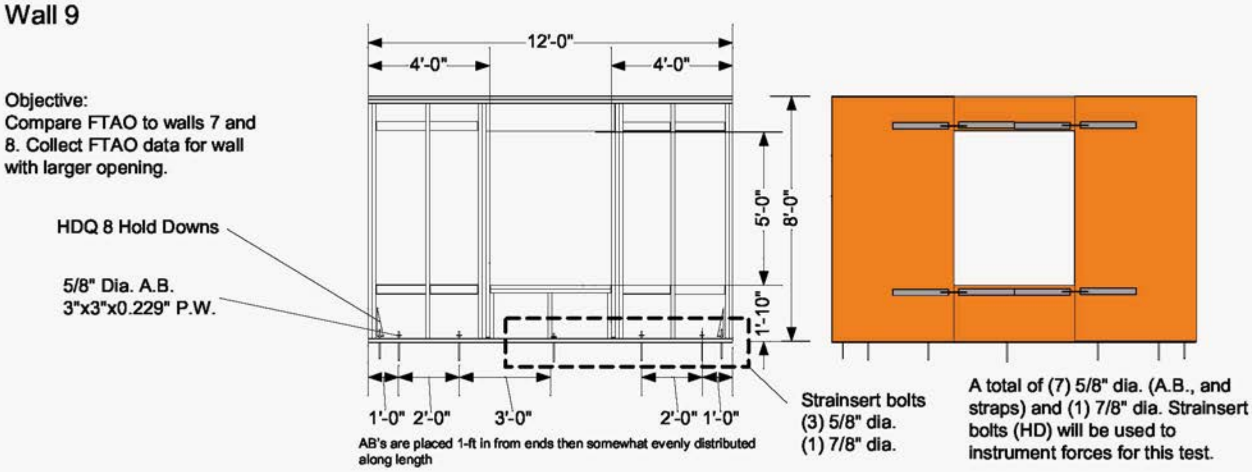
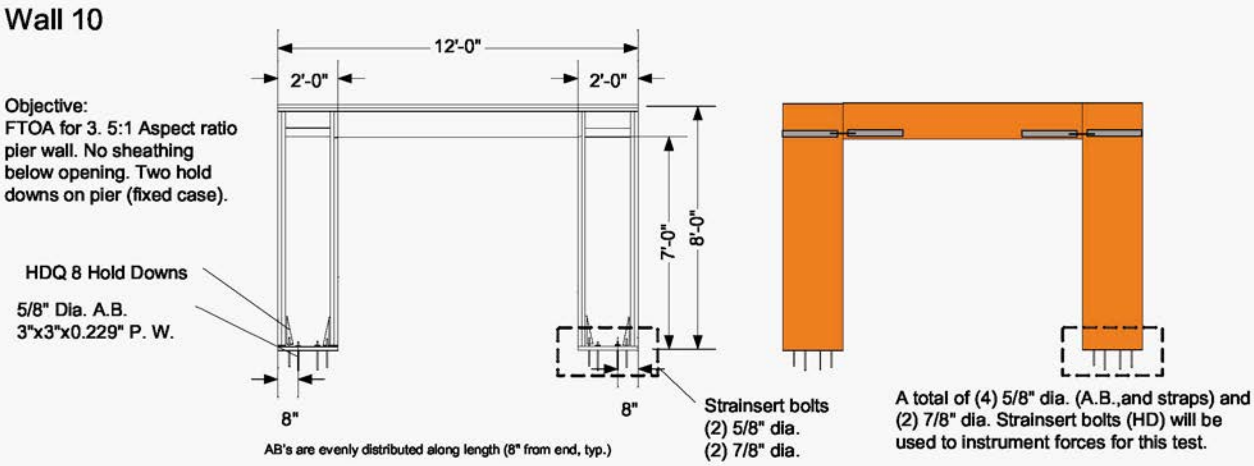
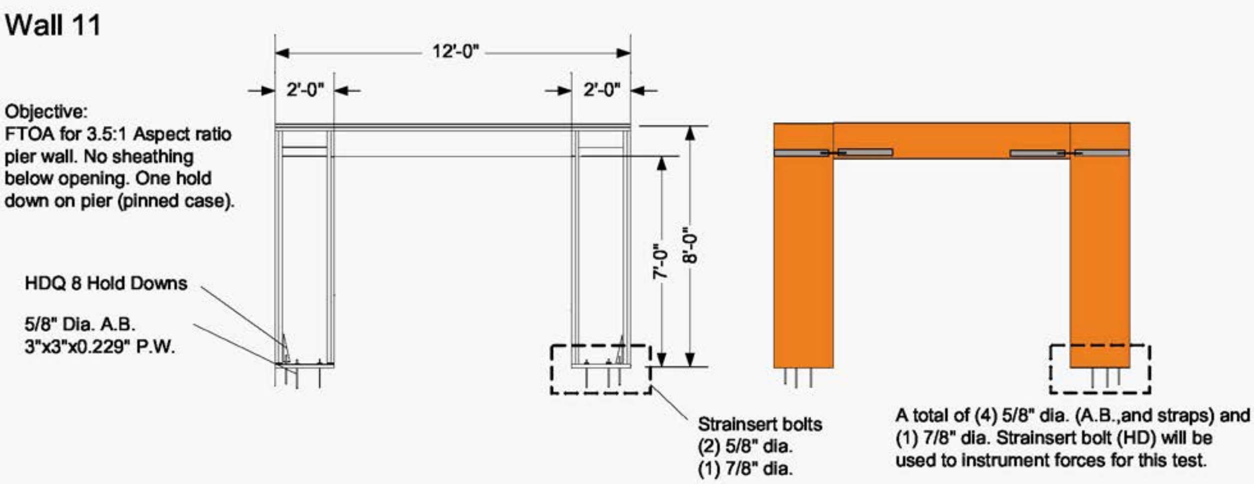
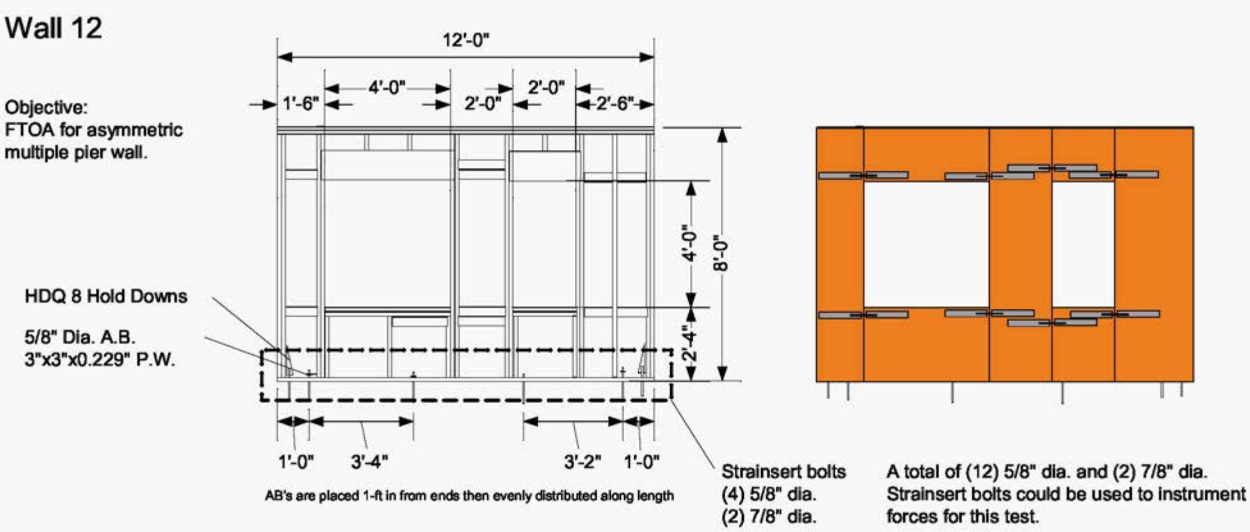


FIGURE 3 (Continued)

FRAMING PLANS (RIGHT) AND SHEATHING PLANS (LEFT) FOR VARIOUS FORCE TRANSFER AROUND OPENINGS ASSEMBLIES







1.3 RESULTS

Global Response

Cyclic hysteretic plots and various cyclic parameters of the individual walls are provided in Appendix A of this report. Monotonic plots are provided in Appendix B, hold-down force plots are provided in Appendix C, and finally anchor bolt forces plots are provided in Appendix D of this report. Figure 4 are hysteric plots of the applied load versus the displacement of the walls. The response curves are representative for all walls tested. One can observe the relatively increased stiffness of perforated shear walls (Wall 2) versus the segmented walls (Wall 1). However, the relatively brittle nature of the perforated walls should be noted as the perforated shear walls resulted in sheathing tearing. As one might expect, the walls detailed for force transfer around openings (Wall 4d and 5d) demonstrated increased stiffness as well as strength over the segmented walls. In addition, the response of the walls was related to opening sizes with the larger openings resulting in both lower stiffness and lower strength.

FIGURE 4

HYSTERETIC BEHAVIOUR OF VARIOUS WALLS, TYPICAL OF THE CYCLIC TESTS

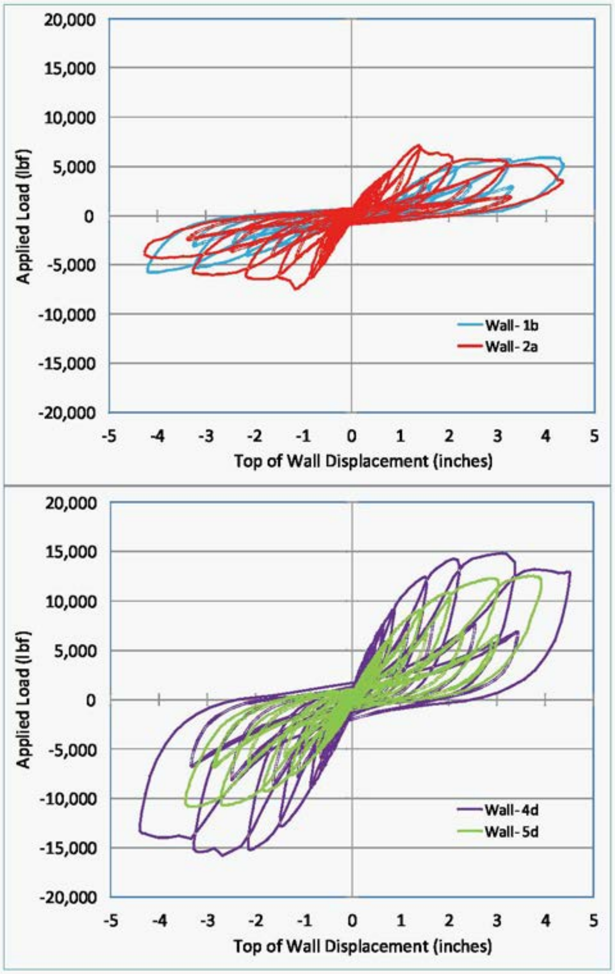


Table 1 represents the maximum loads resisted by the various walls and calculated load factors. The expected wall capacity is based on the code listed allowable unit shear multiplied by the effective length of the wall, as determined by the sum of the lengths of the full-height piers. For the perforated shear walls, a further factor of C_o was included. Table 1 also provides measured hold-down forces as observed when the wall was subjected to ASD unit shear, which resisted overturning of the segments.

TABLE 1

GLOBAL RESPONSE OF TESTED WALLS

Wall ID	ASD Unit Shear(1), V (plf)	Effective Wall Length(2) (ft)	Wall Capacity(3) (lbf)	Average Applied Load to Wall (lbf)	ASD Load Factor(A)	Outboard Hold-down Force (lbf)	Inboard Hold-down Force (lbf)	Load Head
Wall 1a	870	4.5	3,915	5,421	1.4	7,881	5,313	Short
Wall 1b		4.5	3,915	5,837	1.5	6,637	6,216	Short
Wall 2a		4.5	3,631	7,296	1.9	2,216		Short
Wall 2b		4.5	3,631	6,925	1.8	3,248		Long
Wall 3a		4.5	3,631	10,370	2.6	2,602		Short
Wall 3b		4.5	3,631	8,955	2.3	4,090		Long
Wall 4a		4.5	3,915	14,932	3.8	1,140		Short
Wall 4b		4.5	3,915	17,237	4.4	3,674		Intermediate
Wall 4c(5)		4.5	3,915	17,373	4.4	1,336		None
Wall 4d		4.5	3,915	15,328	3.9	1,598		Intermediate
Wall 5b		4.5	3,915	13,486	3.4	5,216		Intermediate
Wall 5c(5)		4.5	3,915	11,887	3.0	4,795		None
Wall 5d		4.5	3,915	11,682	3.0	4,413		Long
Wall 6a		4.5	3,915	11,948	3.1	1,573		Long
Wall 6b		4.5	3,915	13,582	3.5	1,285		Long
Wall 7a		a	6,960	12,536	1.8	6,024	3,677	Short
Wall 7b		a	6,960	10,893	1.6	6,577	3,844	Long
Wall 8a		a	6,960	15,389	2.2	4,805		Long
Wall 8b (6)		a	6,960	15,520	2.2	5,548		Long
Wall 9a		a	6,960	15,252	2.2	4,679		Long
Wall 9b		a	6,960	16,647	2.4	5,212		Long
Wall 10a		4	3,480	7,473	2.1	5,311	5,690	Long
Wall 10b		4	3,480	6,976	2.0	4,252	3,731	Long
Wall 11a		4	3,480	6,480	1.9	6,449		Long
Wall 11b		4	3,480	5,669	1.6	5,843		Long
Wall 12a		6	5,220	16,034	3.1	2,856		Long
Wall 12b		6	5,220	15,009	2.9	3,458		Long

(1) Typical tabulated values are based on allowable stress design (ASD) unit shear.

(2) Based on sum of the lengths of the full-height segments of the wall.

(3) The shear capacity of the wall, V, is the sum of the full-height segments times the unit shear capacity. For "perforated shear walls" (Walls 2 & 3), this capacity was multiplied by C_o = 0.93. No reduction was taken based on aspect ratio of the walls.

(4) Wall capacity divided by the average load applied to the wall.

(5) Monotonic test.

(6) Loading time increased by 10x.

In general, the segmented walls (Wall 1 and Wall 7) resulted in the lowest load factors of the walls tested. The perforated shear wall (Wall 2) also performed at a lower level than the walls specifically detailed with force transfer around openings. Surprisingly, the compression blocking with no straps (Wall 3a) resulted in a significantly improved performance over Wall 2. Another general observation is that the larger the wall opening, the lower the load factors. The wall global behaviour seemed to be insensitive to the different loading rate (Walls 8a and 8b). In addition, the walls with typical window openings that are sheathed both above and below openings, and the walls with the narrowest piers (height-to-width ratios of 3.5:1) based on the minimum pier width permitted in the North American codes (Walls 3, 4, 5 and 6) resulted in higher load factors than walls with full-width piers at a height-to-width ratio of 2:1 (Walls 7, 8 and 9).

A variety of failure modes were observed, as shown in Appendix F. In general, lumber failure was not a significant limit state with the exception of the wall shown in Figure F1. The more typical failure modes were related to wood panel tearing around the openings, as illustrated in Figures F5 through F8, and F12. The traditional shear walls (Walls 1 and 7) showed more classic failure modes. Figure F9 illustrates a typical failure mode of nail head pulling out of the side of the panel. Nail head pullout was also a common failure mode, as illustrated in Figure F10.

Table 1 also lists the average outboard hold-down response of the walls, when the walls were subjected to the ASD design load. The data is not conclusive on the effect of the load head length on the overturning hold-down forces. The repeatability of the hold-down forces was not as good as the overall global response of the walls. Wall 4b had relatively high hold-down forces, but did not match well with the other hold-down forces observations on Wall 4. Given the lack of conclusive data, only observations can be provided. Based on comparisons of Walls 5c and 5d, the difference between no load head and the long load head appears to be relatively minor. In general, the long load head appears to lead to relatively higher hold-down forces as compared to the short load head (Wall 2a vs 2b and Wall 7a vs 7b). As a recommendation for future tests on force transfer around openings, the load head should not be in direct contact with the top of the wall so that the top plate is not stiffened by the load head, and more importantly, avoiding a parallel force transfer load path via the load head. Cyclic hysteretic plots and various cyclic parameters of the individual walls are provided in Appendix A of this report. The backbone curves and the equivalent energy elastic-plastic curves were analyzed by an Excel spreadsheet, which follows the procedures outlined in ASTM E2126. Monotonic plots are provided in Appendix B,

Hold-down, Anchor Bolt and Strap Force Responses

The hold-down force plots are provided in Appendix C of this report. The internal forces around openings were measured with calibrated tension bolts, as discussed in the test plan above (also see Figures F12 and F13). The anchor bolt uplift force plots are provided in Appendix D. Finally, the strap forces plots are presented in Appendix E. Figure 5 illustrates the notation of the force gages as well as a typical response curve of wall load versus internal force around opening. The response curves show hysteretic behaviour, which is likely due to cumulative damage of the wall as well as the orientation of the bolt recording tension forces as may be influenced by the differential displacement of the hold-down seats in the vertical direction. Deflection measurements may potentially be used to correct the load to “pure horizontal tension.” However, in the range of the wall ASD values, the internal load response was relatively linear elastic.

Table 2 provides a summary of the predicted forces based on the various techniques. Table 3 provides a comparison of the measured internal forces at the wall at the allowable value to the predicted strap forces. The measured internal forces were taken at the cycle in which the walls were loaded to the allowable design value.

FIGURE **5**

NOTATION OF INTERNAL FORCE GAGES (TOP FIGURE), AND TYPICAL RESPONSE CURVE (BOTTOM FIGURE)

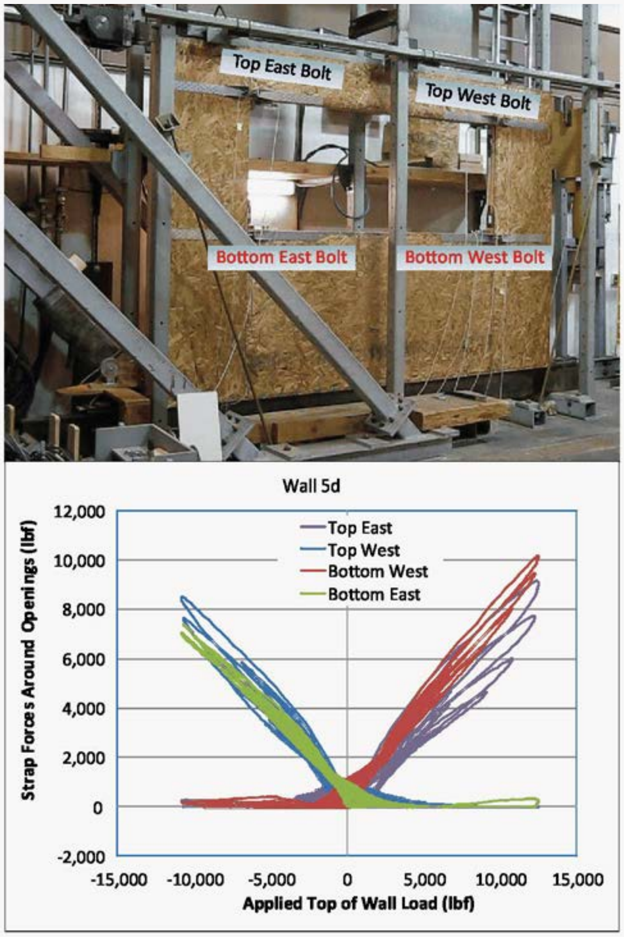


TABLE **2**

PREDICTED STRAP FORCES AT THE ASD DESIGN CAPACITY OF THE WALLS

	Predicted Strap Forces at ASD Capacity (lbf)				
	Drag Strut Technique		Cantilever Beam Technique		Diekmann Technique
Wall ID	**Top**	**Bottom**	**Top**	**Bottom**	**Top/Bottom**
Wall 4	1,223	1,223	4,474	2,724	1,958
Wall 5	1,223	1,223	6,151	4,627	3,263
Wall 6	1,223	1,223	4,474	2,724	1,958
wall 8	1,160	1,160	7,953	4,842	1,856
Wall 9	1,160	1,160	7,953	6,328	3,093
Wall 10	1,160	n.a. (1)	7,830	n.a. (1)	n.a. (1)
Wall11	1,160	n.a. (1)	7,830	n.a. (1)	n.a. (1)
Wall 12	653	1,088	4,784	4,040	1,491

(1) Notapplicable.

TABLE 3

INTERNAL FORCES OF TESTED WALLS AT THE ASD DESIGN CAPACITY AS COMPARED TO VARIOUS PREDICTED STRAP FORCES

Wall ID	Measured Strap Forces (lbf)(1)		Error(2) for Predicted Strap Forces at the ASD Design Value				
			Drag Strut Technique		Cantilever Beam Technique		Diekmann Technique
	Top	Bottom	Top	Bottom	Top	Bottom	Top/Bottom
Wall 4a	687	1,485	178%	82%	652%	183%	132%
Wall 4b	560	1,477	219%	83%	800%	184%	133%
Wall 4c(3)	668	1,316	183%	93%	670%	207%	149%
Wall 4d	1,006	1,665	122%	73%	445%	164%	118%
Wall 5b	1,883	1,809	65%	68%	327%	256%	173%
Wall 5c(3)	1,611	1,744	76%	70%	382%	265%	187%
Wall 5d	1,633	2,307	75%	53%	377%	201%	141%
Wall 6a	421	477	291%	256%	1,063%	571%	410%
Wall 6b	609	614	201%	199%	735%	444%	319%
Wall 8a	985	1,347	118%	86%	808%	359%	138%
Wall 8b(4)	1,493	1,079	78%	108%	533%	449%	124%
Wall 9a	1,675	1,653	69%	70%	475%	383%	185%
Wall 9b	1,671	1,594	69%	73%	476%	397%	185%
Wall 10a	1,580	n.a.(5)	73%	n.a.(5)	496%	n.a.(5)	n.a.(5)
Wall 10b	2,002	n.a.(5)	58%	n.a.(5)	391%	n.a.(5)	n.a.(5)
Wall 11a	2,466	n.a.(5)	47%	n.a.(5)	318%	n.a.(5)	n.a.(5)
Wall 11b	3,062	n.a.(5)	38%	n.a.(5)	256%	n.a.(5)	n.a.(5)
Wall 12a	807	1,163	81%	94%	593%	348%	128%
Wall 12b	1,083	1,002	60%	109%	442%	403%	138%

(1) Reported strap forces were based on the mean of the "East" and "West" recorded forces at the capacity of the walls as tabulated in Table 1.

(2) Error based on ratio of predicted forces to mean measured strap forces. For Diekmann method, the larger of the top and bottom strap forces was used for calculation. Highlighted errors represent non-conservative predictions and significant ultra-conservative prediction (arbitrarily assigned as 300%).

(3) Monotonic test.

(4) Loading time increased by 10x.

(5) Not applicable.

As shown in Table 3, the measured strap forces were based on the mean east and west strap forces for the top and bottom of the opening. As demonstrated in Figure 5, the strap forces were symmetric about the y-axis, thus averaging strap forces was justifiable.

Model Comparisons to Experimental Strap Forces

Table 2 provides the predicted strap forces at the wall ASD value for the three techniques discussed above. The calculation of these forces is beyond the scope of this paper. However, Martin (2005) covers the drag strut and cantilever beam calculations, and Breyer (2007) covers the Diekmann calculations.

The Diekmann technique assumes symmetric forces at the top and bottom of the window opening to wall interface; hence the maximum of the two measured strap forces was used for the error calculation in Table 3. Also included in Table 2 is the error, in percent, of the calculated strap forces. There is shading for predictions that fall below 100% of the observed strap forces, which would be considered non-conservative. The errors are also shaded when the predictions exceed the measured forces by three times (300%), which are considered excessively conservative.

Several items may be observed from the test results reported in Table 2. The measured strap forces for Wall 6 were smaller than that for the matching wall, Wall 4. This is due to the fact that the forces were transferred through the wrap-around OSB sheathing in Wall 6, thus less demand was placed on the straps. Also, as one would expect, as the openings in the walls increased, the strap forces increased. In addition, as the width of the full-height pier decreased, the relative magnitude of the strap forces increased. The largest strap forces, relative to the applied load, were observed for the large garage-type openings, Walls 10 and 11. Other observations are that the strap forces are reasonably repeatable and that the strap forces are relatively insensitive to loading rate (Walls 8a and 8b) and cyclic versus monotonic loading (Walls 4c and 5c).

Several observations can also be made about the three methods for predicting strap forces. First, the drag strut technique, arguably the simplest method for estimating strap forces, resulted in predicted strap forces that were less than the observed strap forces for nearly every wall. The cantilever beam technique was, by far, the most conservative method. For every wall tested, the cantilever beam technique over-predicted at least one of the strap forces by more than 300 percent. It should also be noted that although the cantilever beam technique decouples the strap forces at the top and the bottom of the window, it always predicted the strap forces at the top of the wall as higher than the bottom of the wall, which is based on the underlying assumption of the moment couples, since the height of the sheathed area above the wall was consistently less than the height of the sheathing below the opening for the walls tested.

Finally the Diekmann technique provided reasonable predicted results (within 190 percent) for all walls with the exception of Wall 6. As discussed above, Wall 6 was an atypical wall since the sheathing wrapped around the opening, thus the forces were transferred through the sheathing as opposed to the strap forces. It is important to note that even though the Diekmann technique provides reasonable prediction, it is still quite crude and extremely conservative in some cases. Improved force transfer around openings design procedures could result in more efficient sizing of straps, blocking, and nailing to transfer forces around openings.

1.4 SUMMARY AND CONCLUSION

Twelve different wall configurations were tested to study the effects of openings on both the global and local responses of walls. The replications showed good agreement between each other, even when test duration was extended to ten times greater the original duration. In terms of the global response, the segmented wall approach resulted in walls with the lowest load factors (based on observed global load divided by allowable capacity of the walls), followed by walls built as perforated shear walls (i.e., no special detailing for forces around openings), and finally the walls specifically detailed for force transfer around openings. In general, as opening sizes were increased, the wall strength and stiffness values were negatively impacted. An unexpected observation was that for walls with typical window openings, the walls with the narrowest piers based on the minimum pier width permitted in the North American codes resulted in higher load factors than walls with full-width piers (height-to-width ratio of 2:1).

Of the twelve wall configurations tested, internal forces were collected on eight of the configurations. For the walls tested, the measured forces at the bottom of the windows were greater than the measured forces at the top of the window. Also, as expected, as the window opening was increased and as the pier width was decreased, the strap forces was increased relative to the global applied force to the wall. Of these eight configurations, it could be concluded that the drag strut technique consistently underestimated the strap forces, and the cantilever beam technique consistently overestimated the strap forces. The Diekmann technique, the most computationally intensive technique, seemed to provide reasonable strap force predictions for the walls with window type openings.

1.6 ACKNOWLEDGEMENTS

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1.6 REFERENCES

1. ASTM International. 2009. *Standard Test Methods for Cyclic (Reversed) Load Test for Shear Resistance of Vertical Elements of the Lateral Force Resisting Systems for Buildings,* ASTM E 2126 - 09. West Conshohocken, PA.

2. ASTM International. 2009. *Standard Practice for Static Load Tests for Shear Resistance of Framed Walls for Buildings,* ASTM E 564 - 06. West Conshohocken, PA.

3. Breyer, D. E., K. J. Fridley, K. E. Cobeen and D. G. Pollock. 2007. *Design of Wood Structures ASD/LRFD,* 6th ed., McGraw Hill, New York, NY.

4. Diekmann, E. F. 1998. *Diaphragms and Shearwalls, Wood Engineering and Construction Handbook,* 3rd ed., K. F. Faherty and T. G. Williamson, eds, McGraw-Hill, New York, NY.

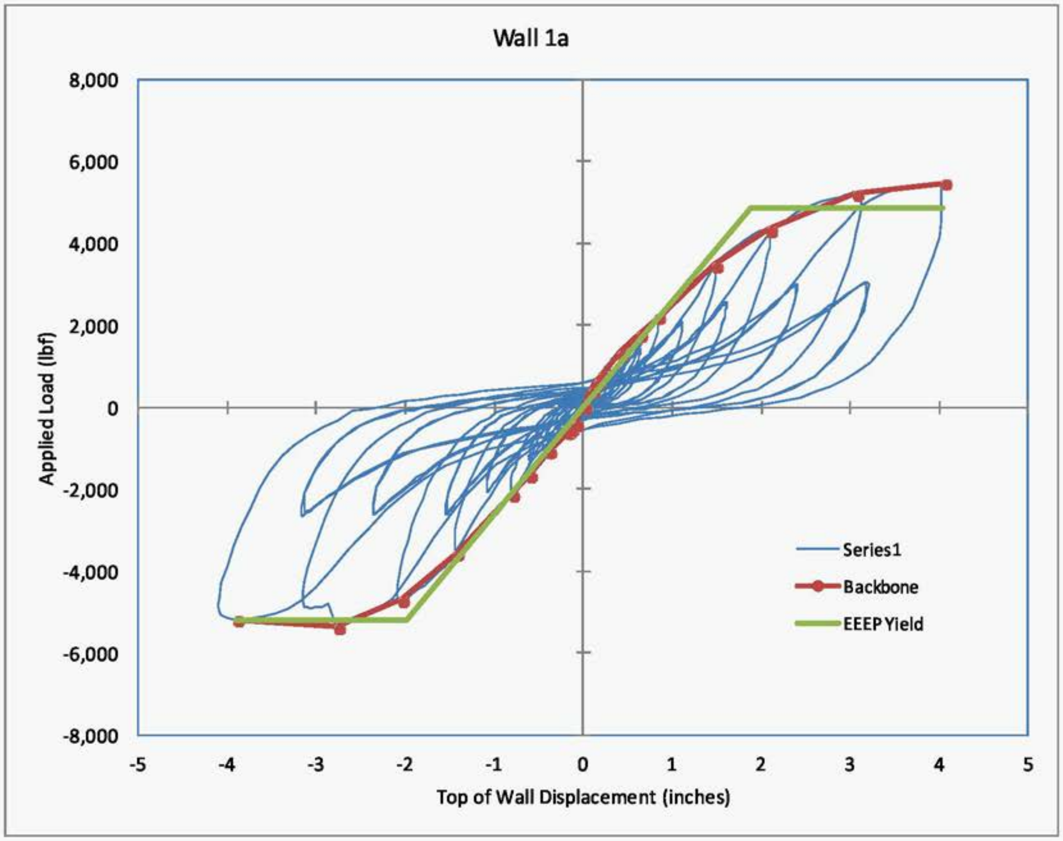
5. Kolba, A. 2000. *The Behavior of Wood Shear Walls Designed Using Diekmann's Method and Subjected to Static In-Plane Loading.* Thesis submitted in partial fulfillment for the degree of Doctor of Philosophy. Marquette University.

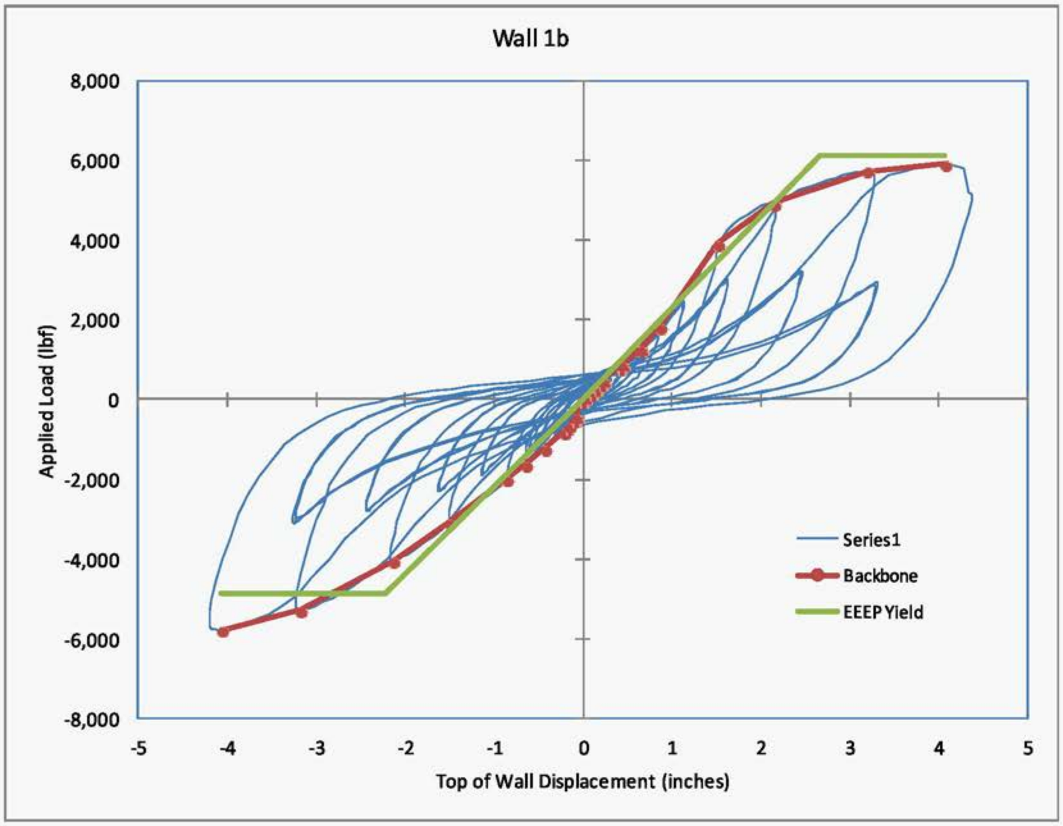
6. Martin, Z. A. 2005. *Design of Wood Structural Panel Shear Walls with Openings: A Comparison of Methods.* Wood Design Focus. 15 (1): 18 - 20.

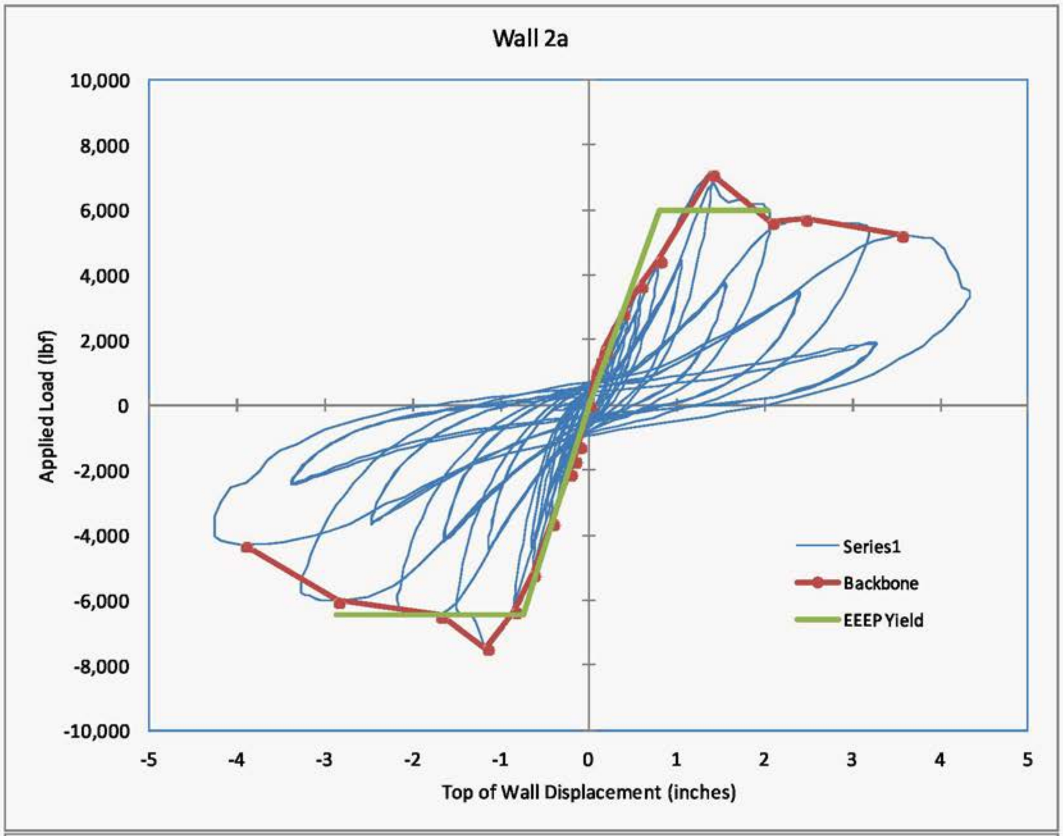
7. SEAOC. 2002. *Seismic Design Manual, Volume II: Building Design Examples - Light Frame, Masonry and Tilt-Up* (1997 UBC), Structural Engineers Association of California, Sacramento, CA.

8. SEAOC Seismology Committee. 2007. "Openings in Wood Frame Shear Walls," January 2007. *The Seaoc Blue Book:* Seismic Design Recommendations. Structural Engineers Association of California, Sacramento, CA.

APPENDIX A – CYCLIC TESTS, GLOBAL WALL DATA



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-4,000
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-8,000
-10,000
-5
-4
-3
-2
-1
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2
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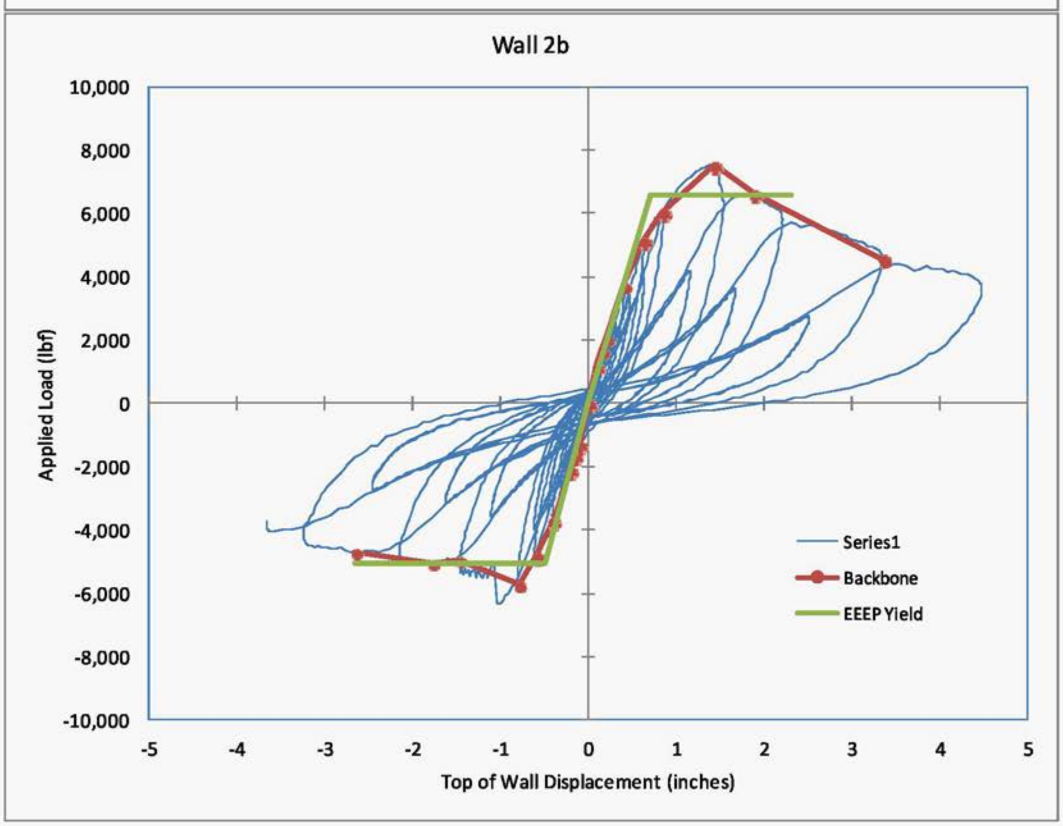
4
5
Top of Wall Displacement (inches)
Series1
Backbone
EEEP Yield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Applied Load (lbf)
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-10,000
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2
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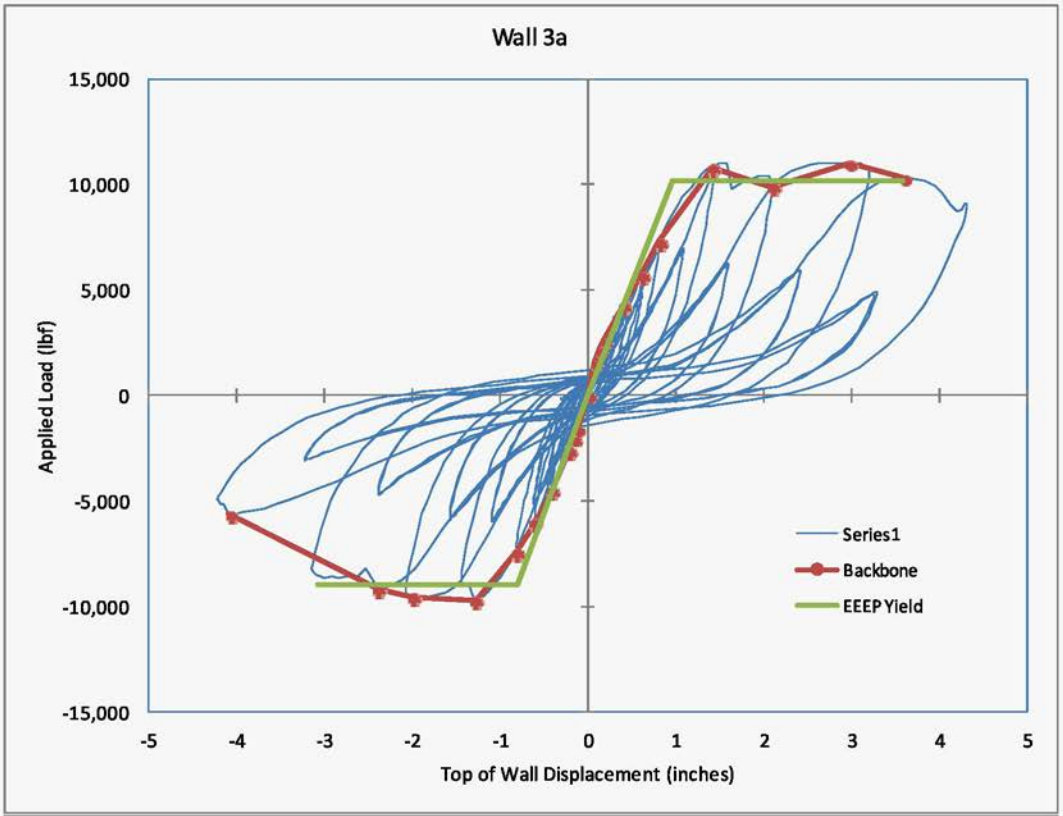
4
5
Top of Wall Displacement (inches)
Series1
Backbone
EEEP Yield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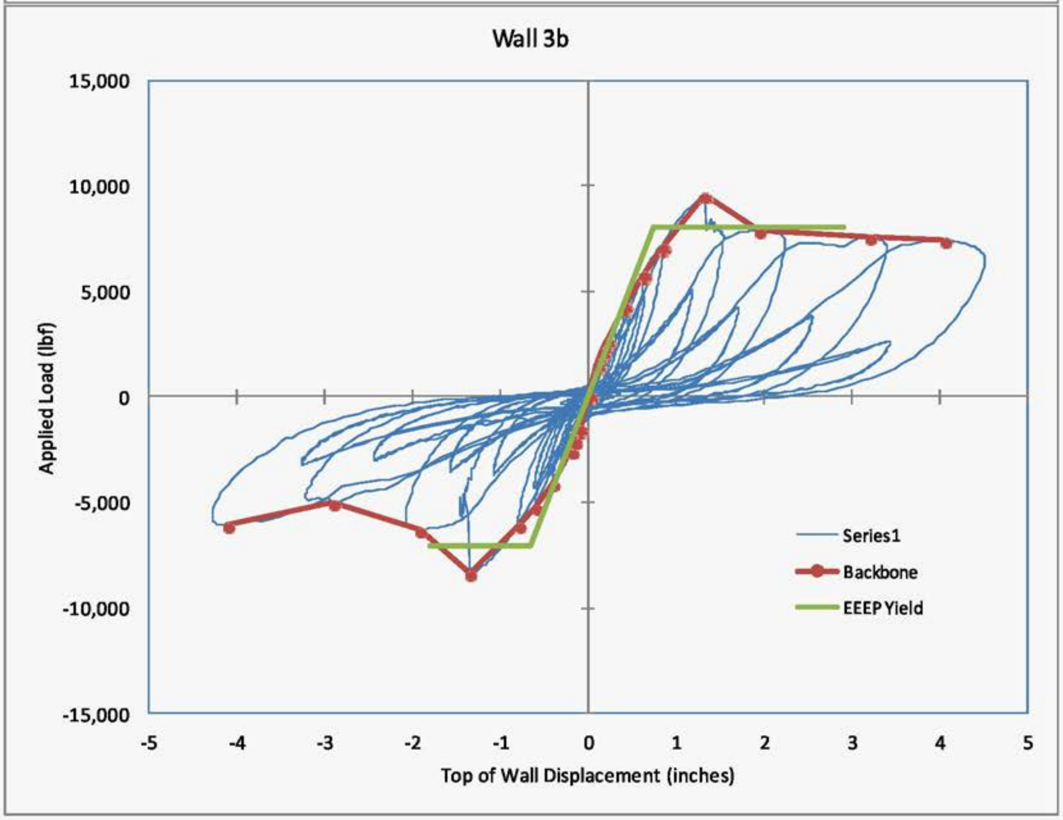
Top of Wall Displacement (inches)
Series1
Backbone
EEEP Yield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2
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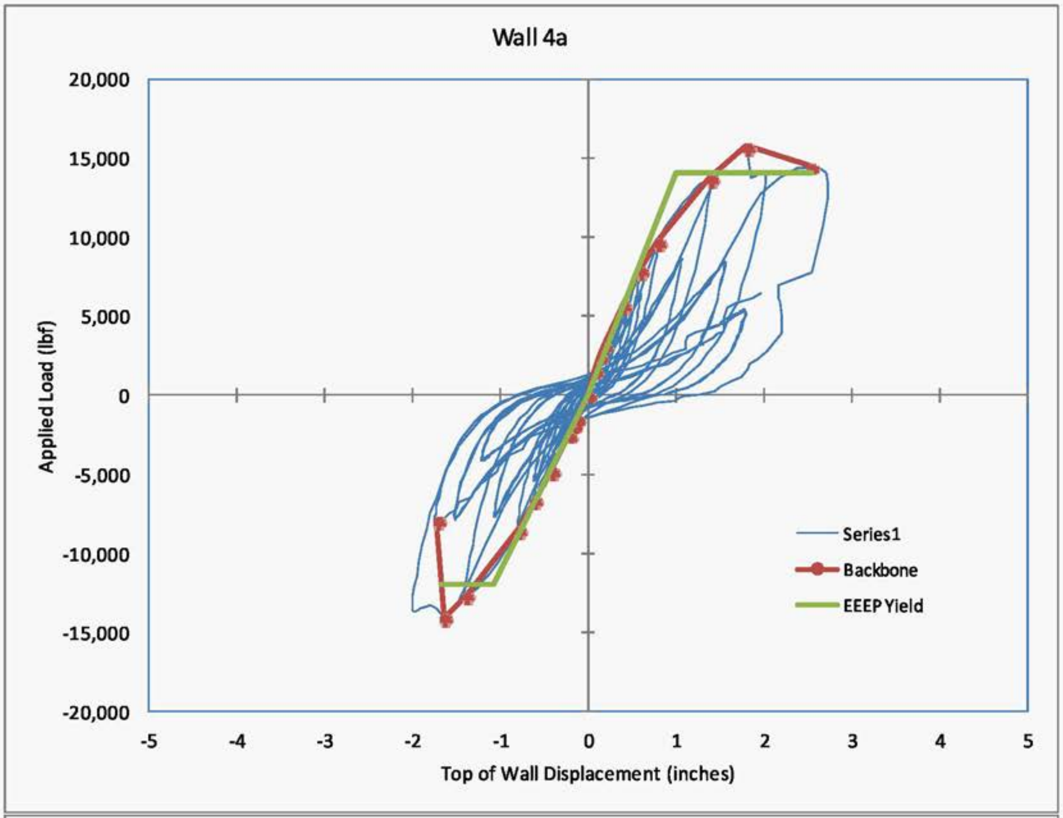
Top of Wall Displacement (inches)
Series1
Backbone
EEEP Yield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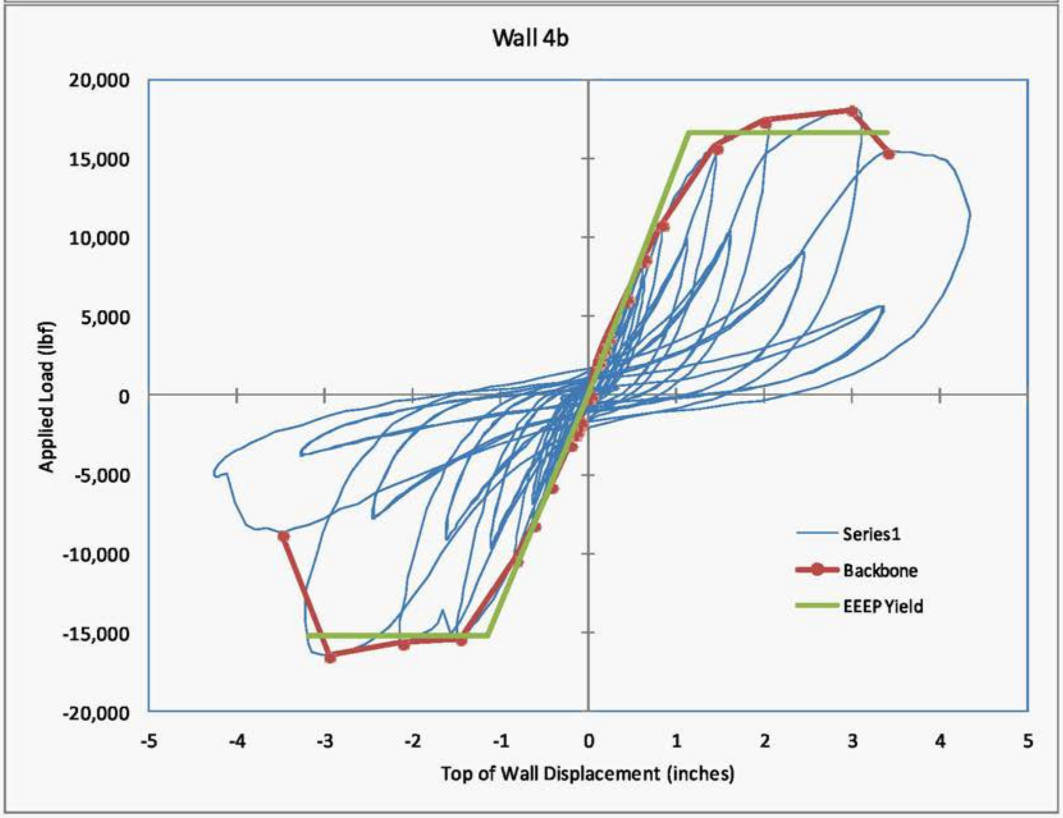
4
5
Top of Wall Displacement (inches)
Series1
Backbone
EEEP Yield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Applied Load (lbf)
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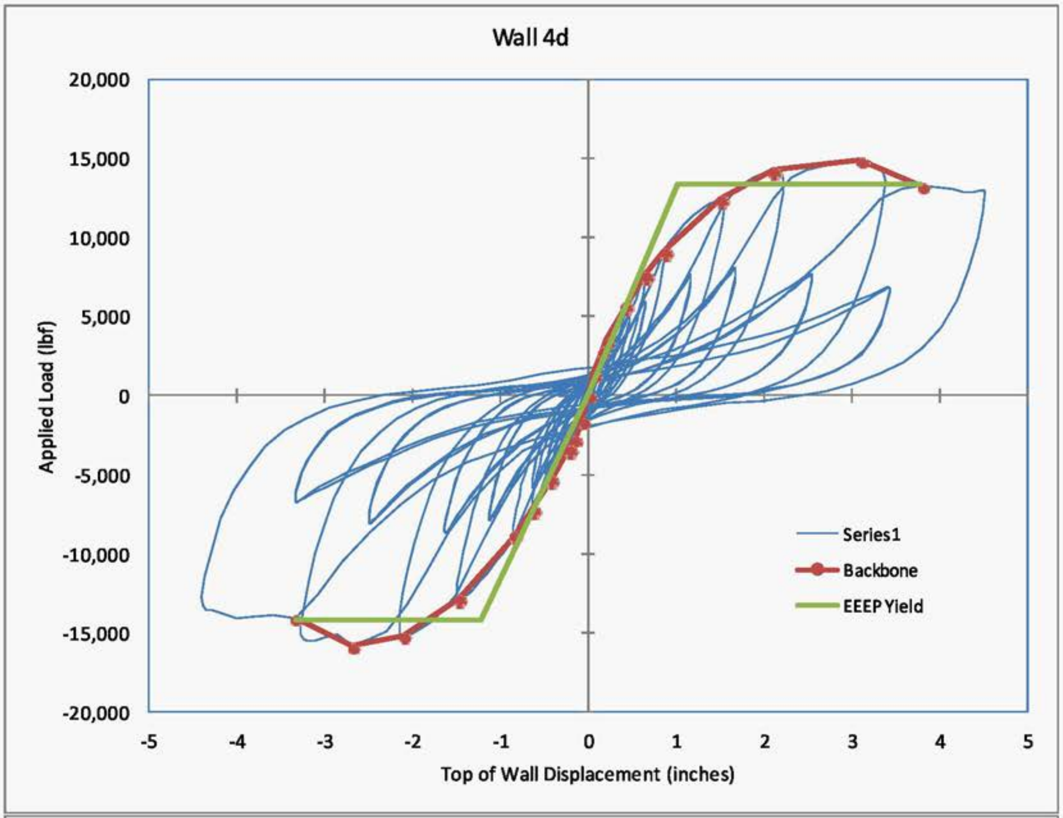
Top of Wall Displacement (inches)
Series1
Backbone
EEEP Yield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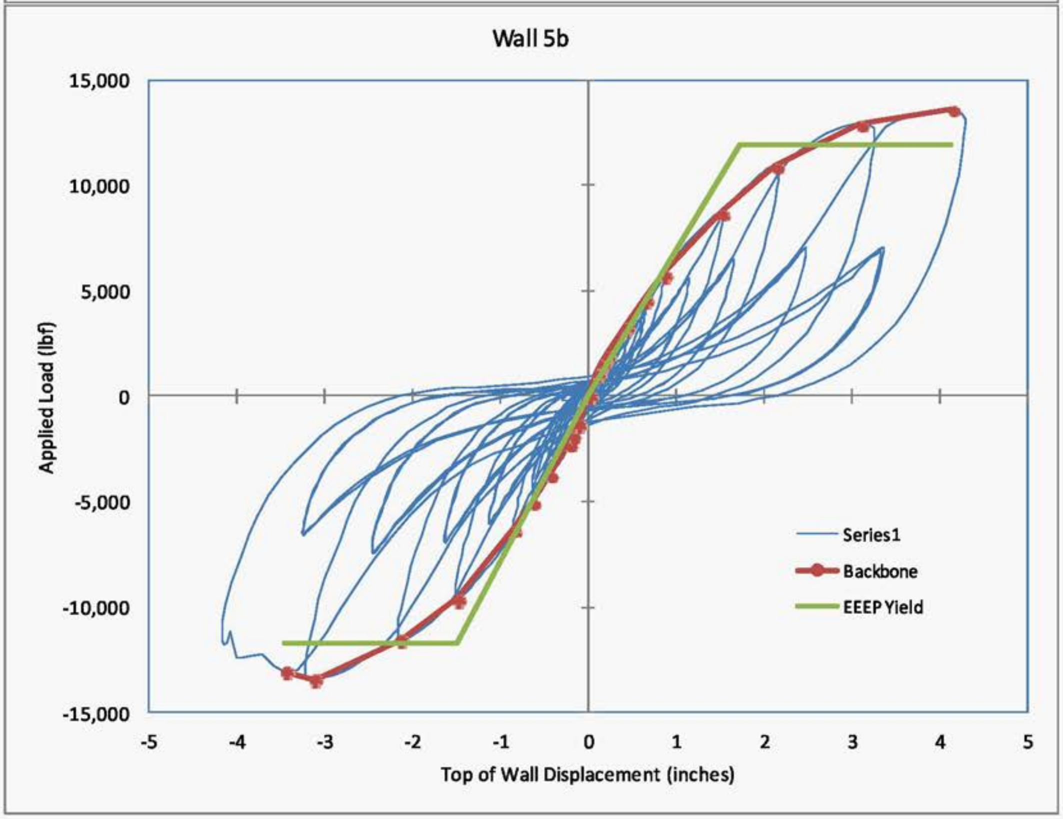
EEEP Yield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Top of Wall Displacement (inches)
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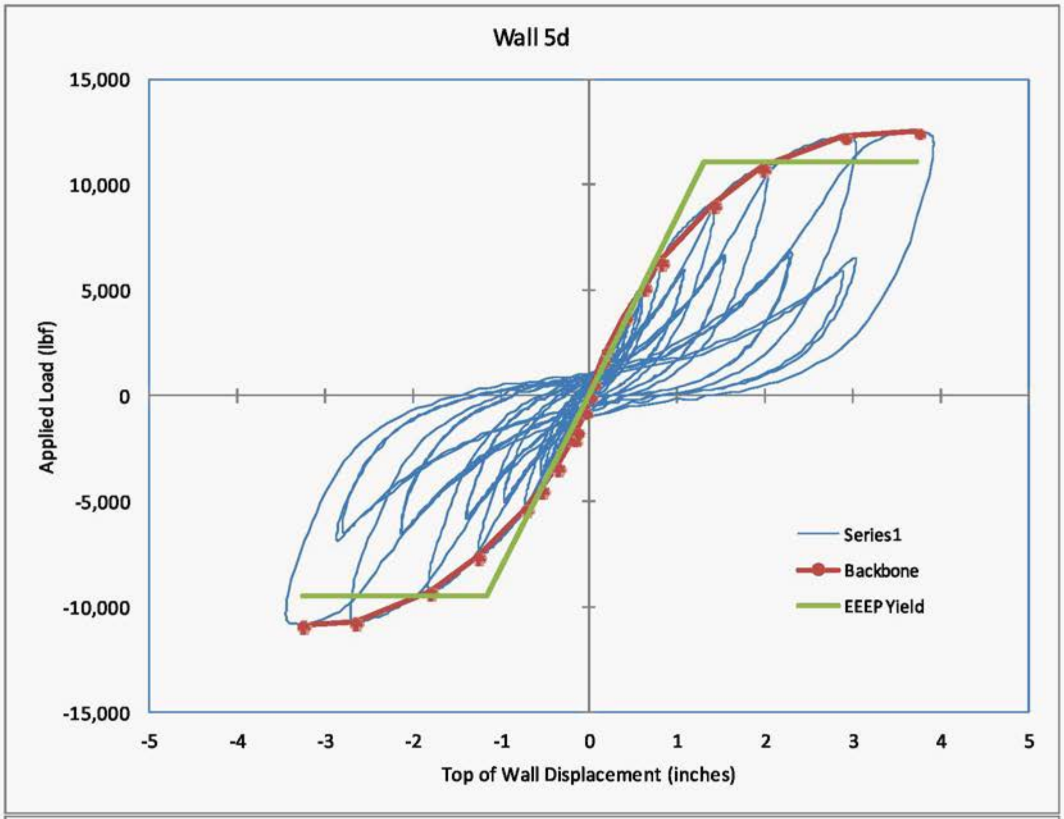
Backbone
EEEP Yield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4
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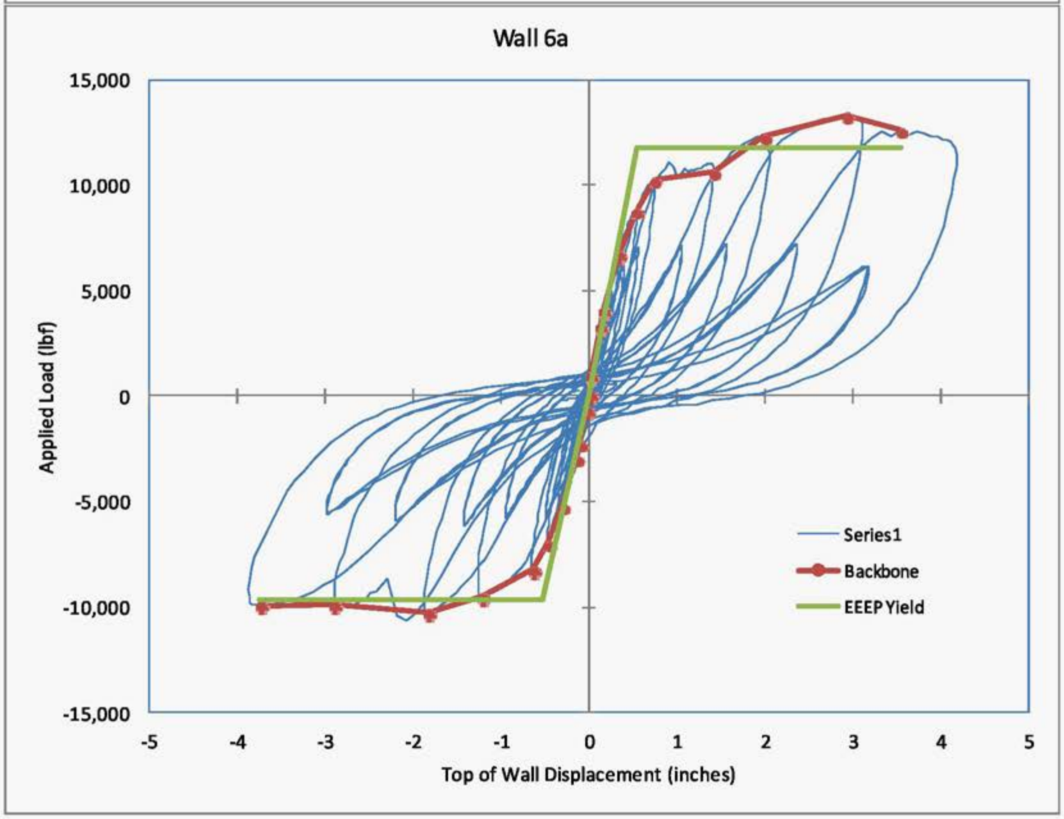
Top of Wall Displacement (inches)
Series1
Backbone
EEEP Yield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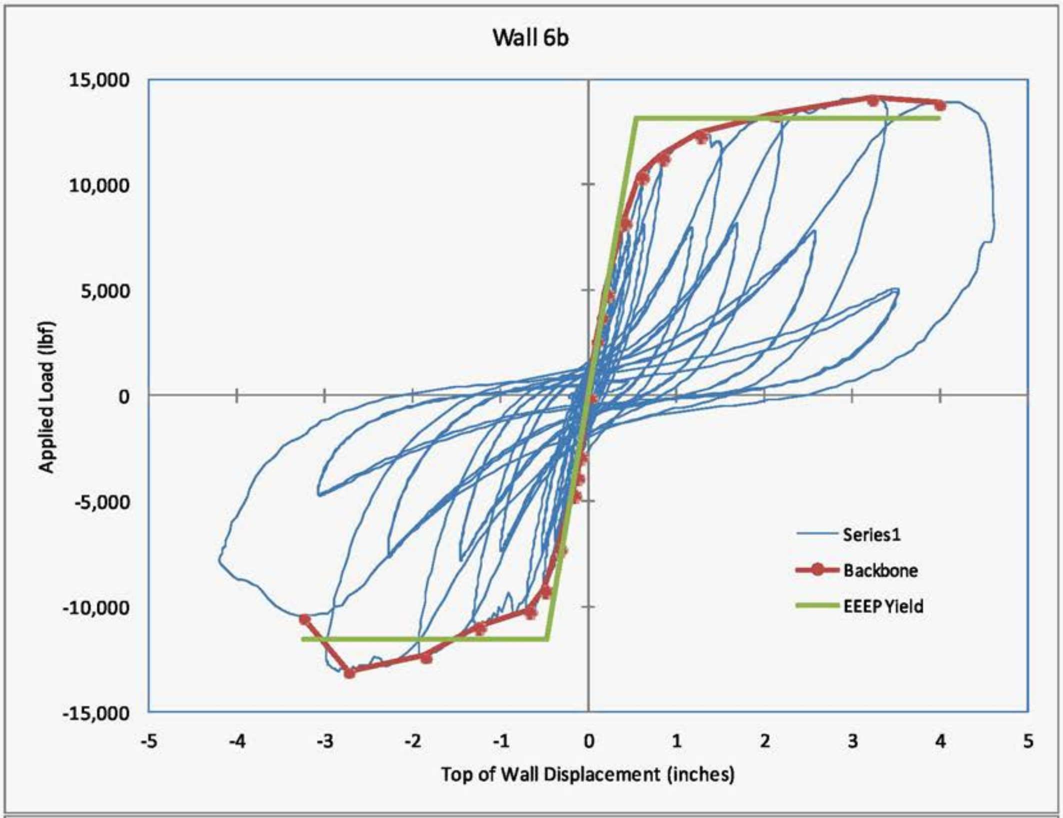
Backbone
EEEP Yield



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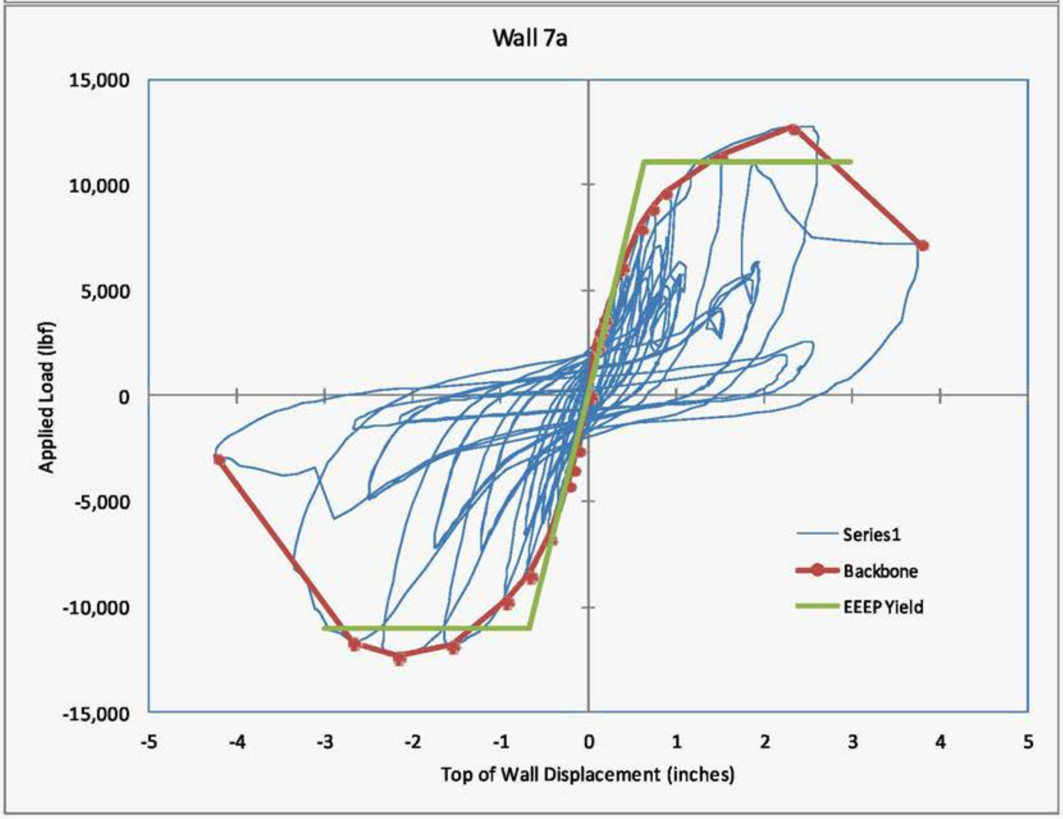
Series1
Backbone
EEEP Yield



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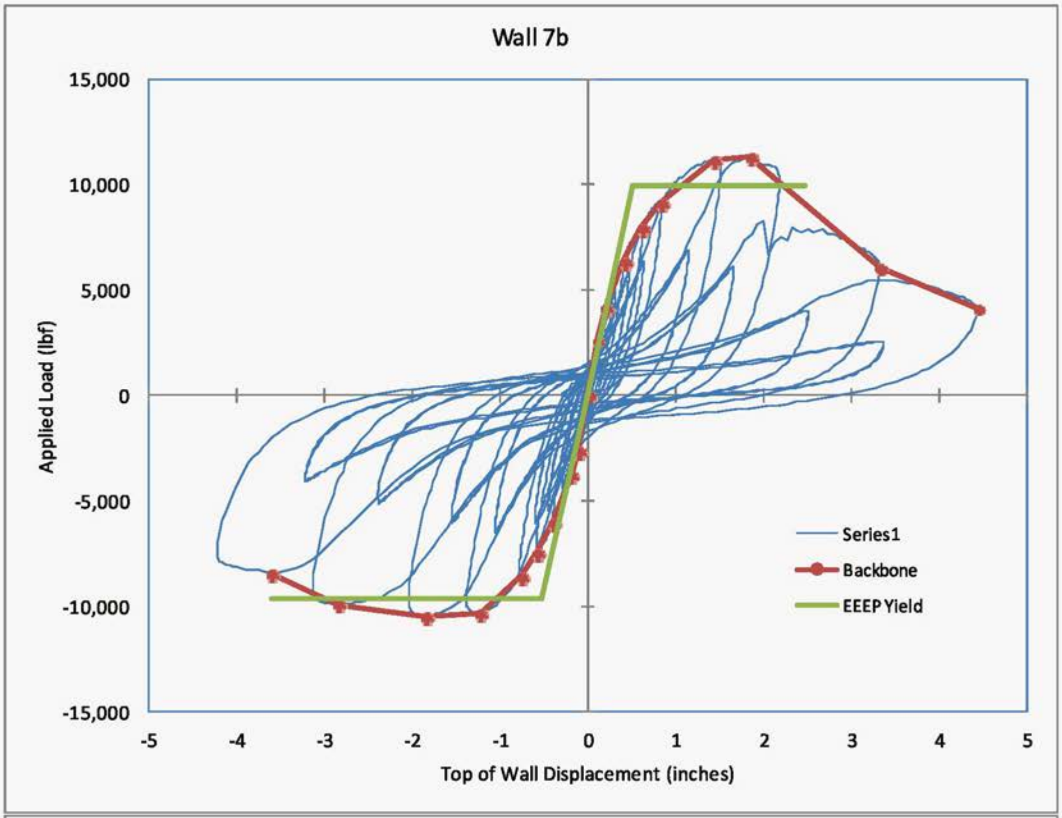
Series1
Backbone
EEEP Yield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Applied Load (lbf)
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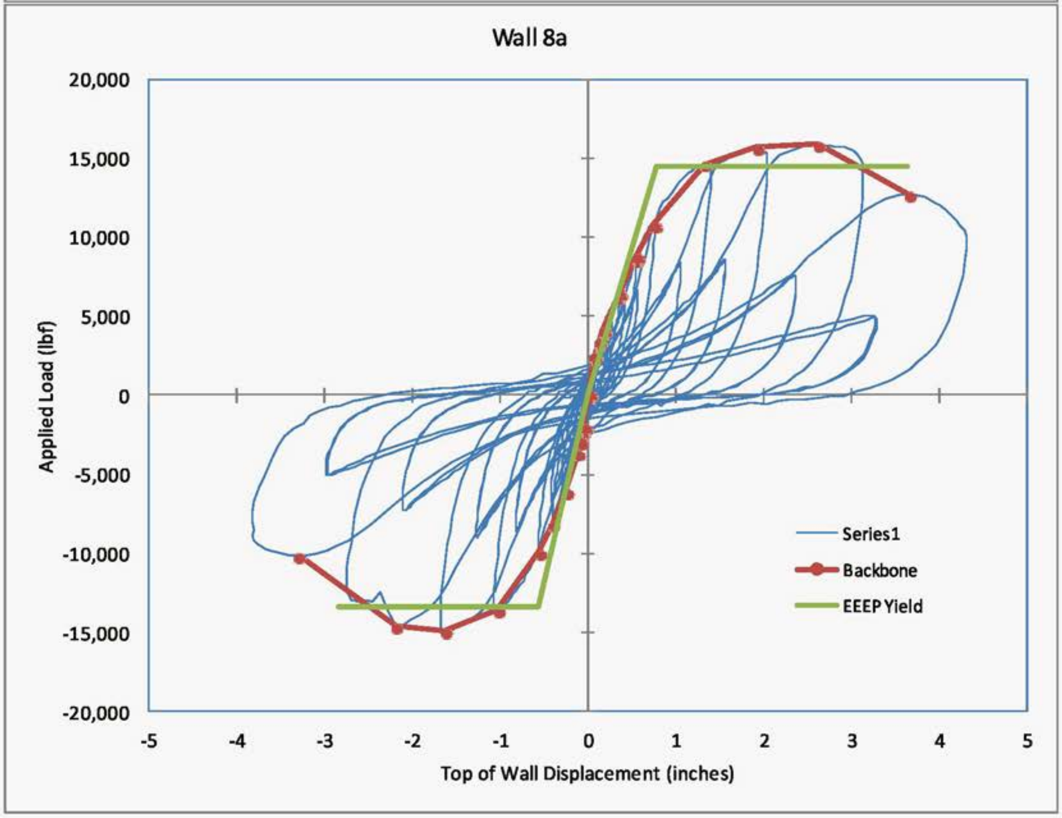
Top of Wall Displacement (inches)
Series1
Backbone
EEEP Yield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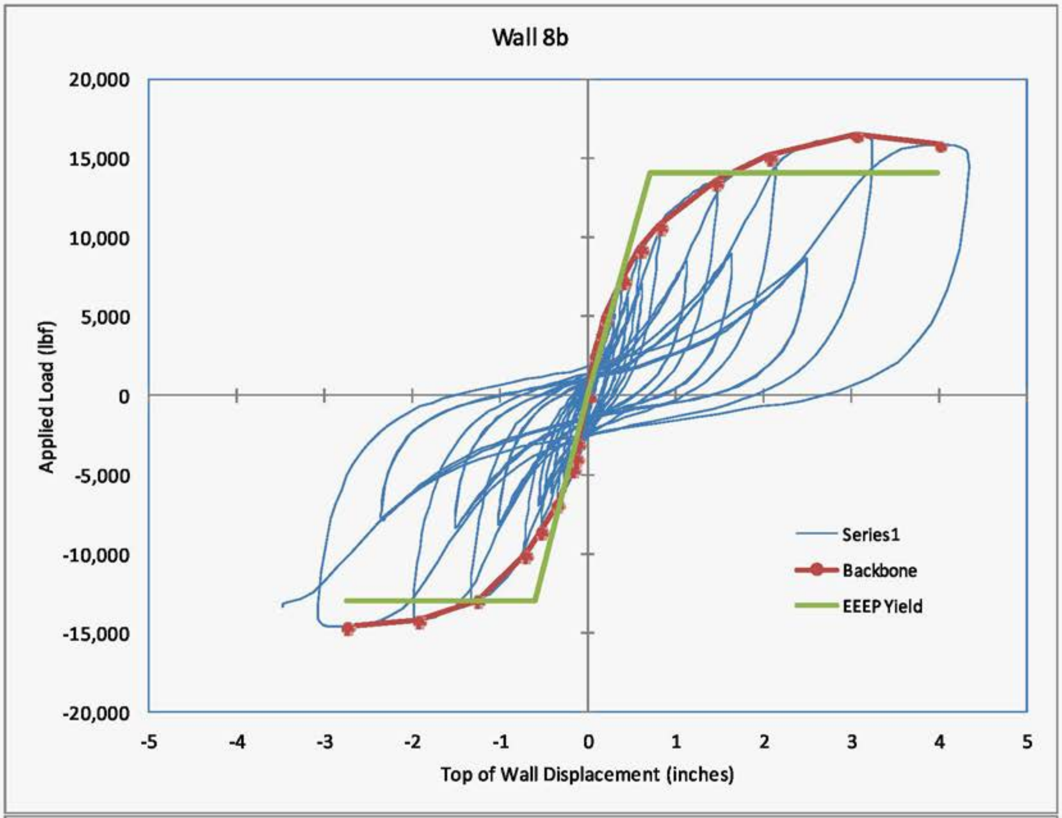
Top of Wall Displacement (inches)
Series1
Backbone
EEEP Yield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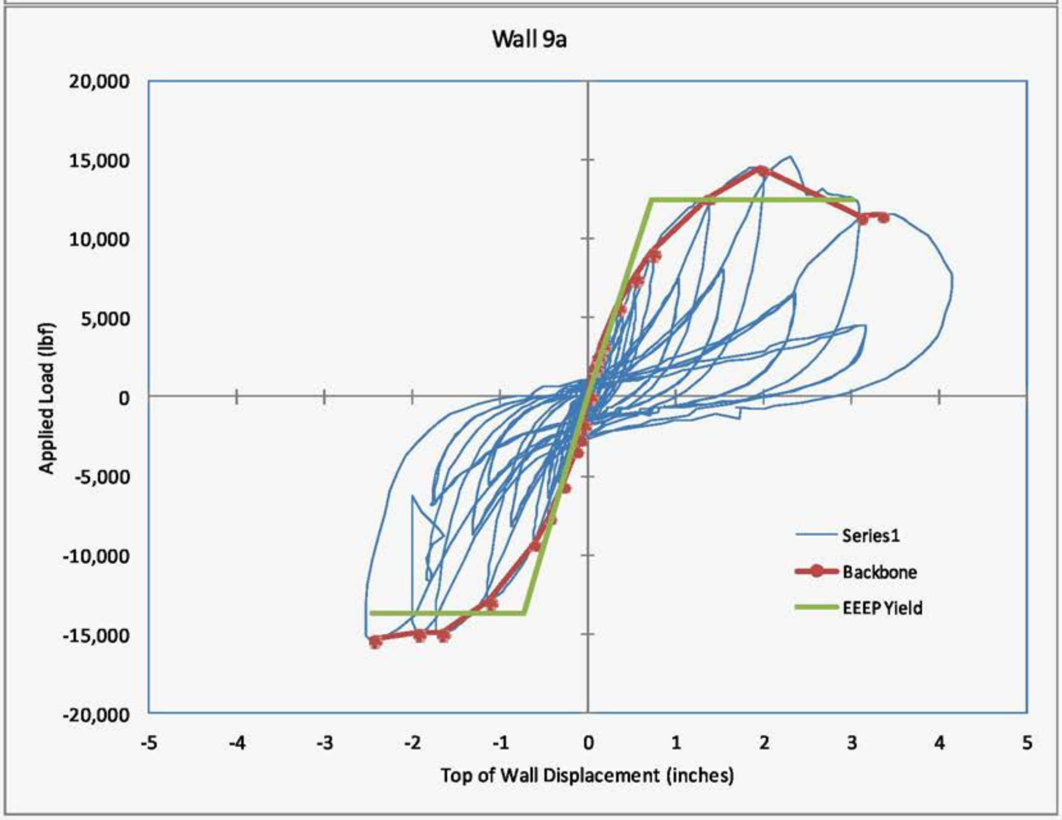
Top of Wall Displacement (inches)
Series1
Backbone
EEEP Yield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Applied Load (lbf)
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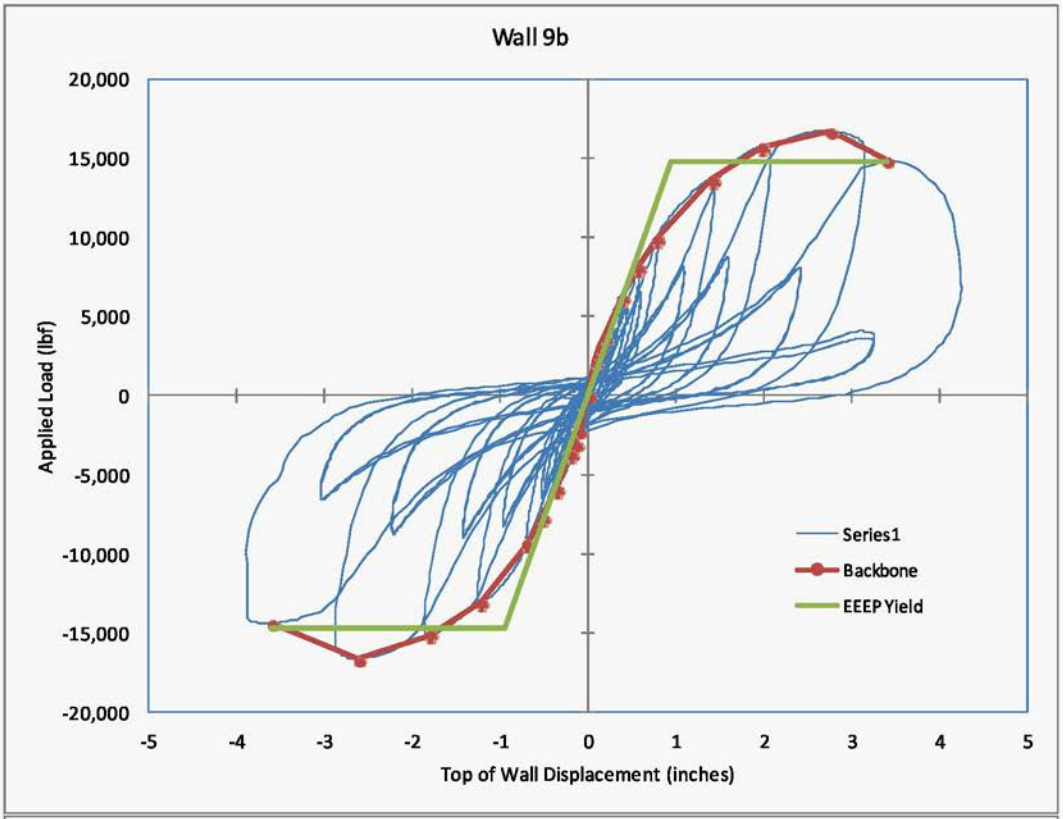
Top of Wall Displacement (inches)
Series1
Backbone
EEEP Yield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Applied Load (lbf)
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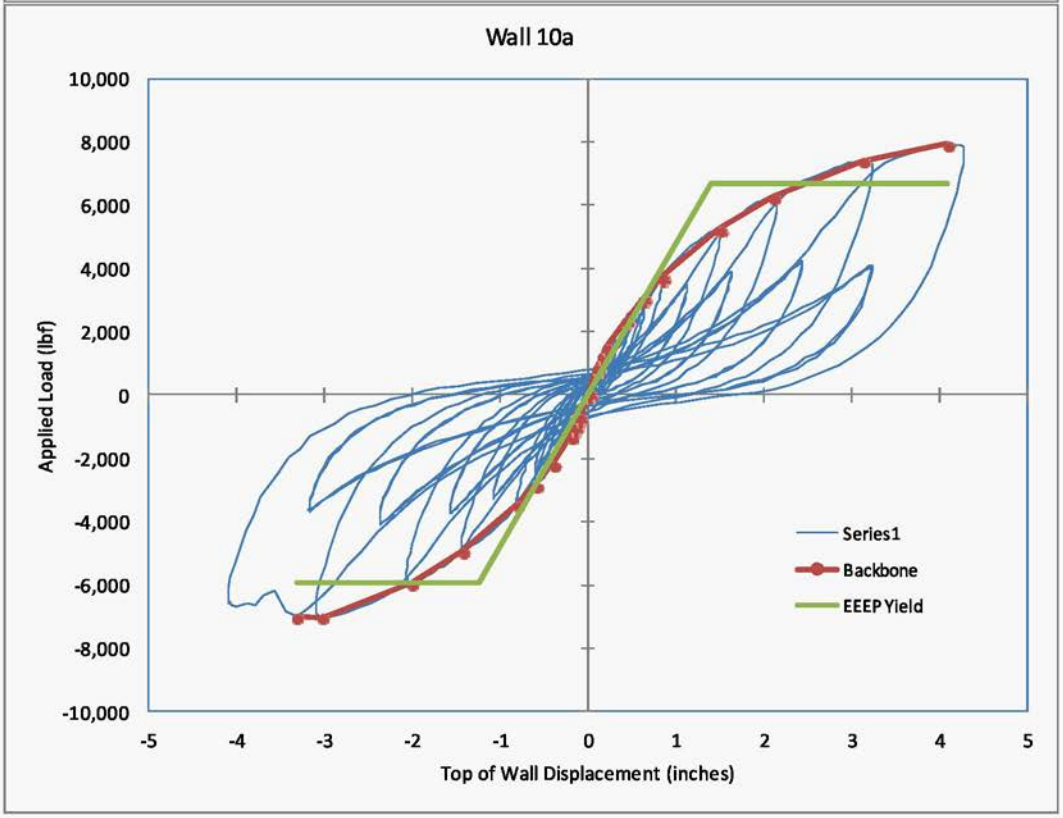
Top of Wall Displacement (inches)
Series1
Backbone
EEEP Yield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Applied Load (lbf)
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-4
-3
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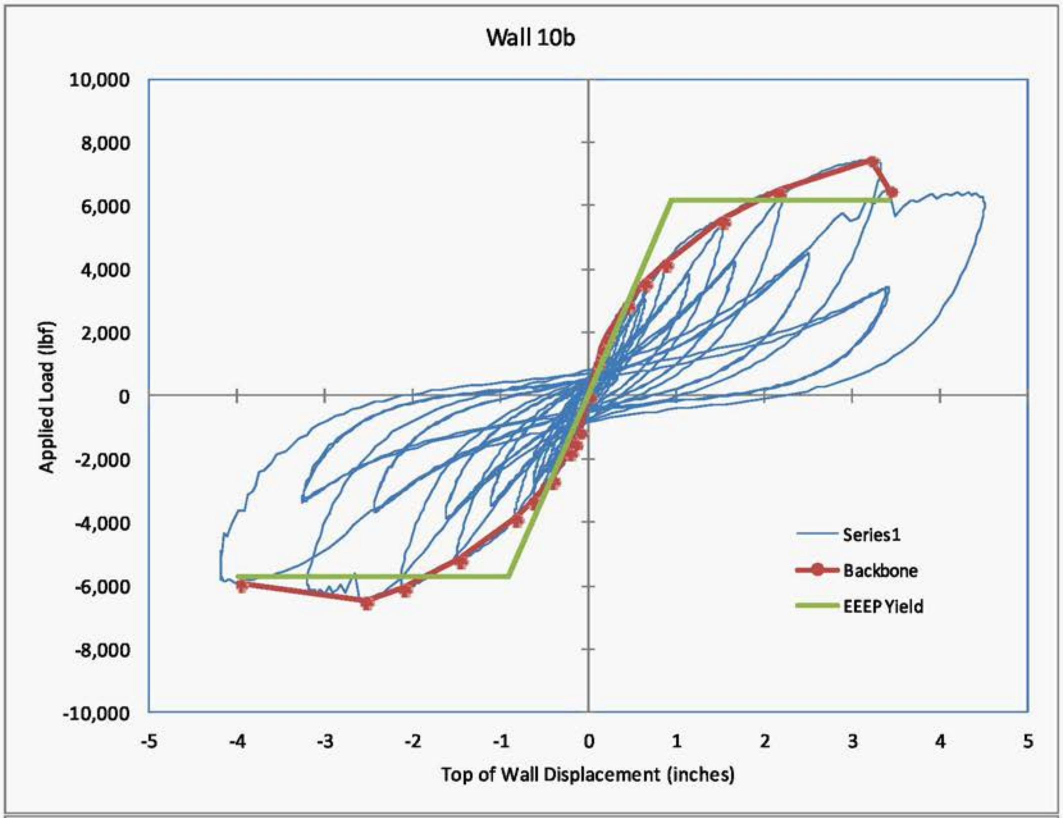
1
2
3
4
5
Top of Wall Displacement (inches)
Series1
Backbone
EEEP Yield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Applied Load (lbf)
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8,000
6,000
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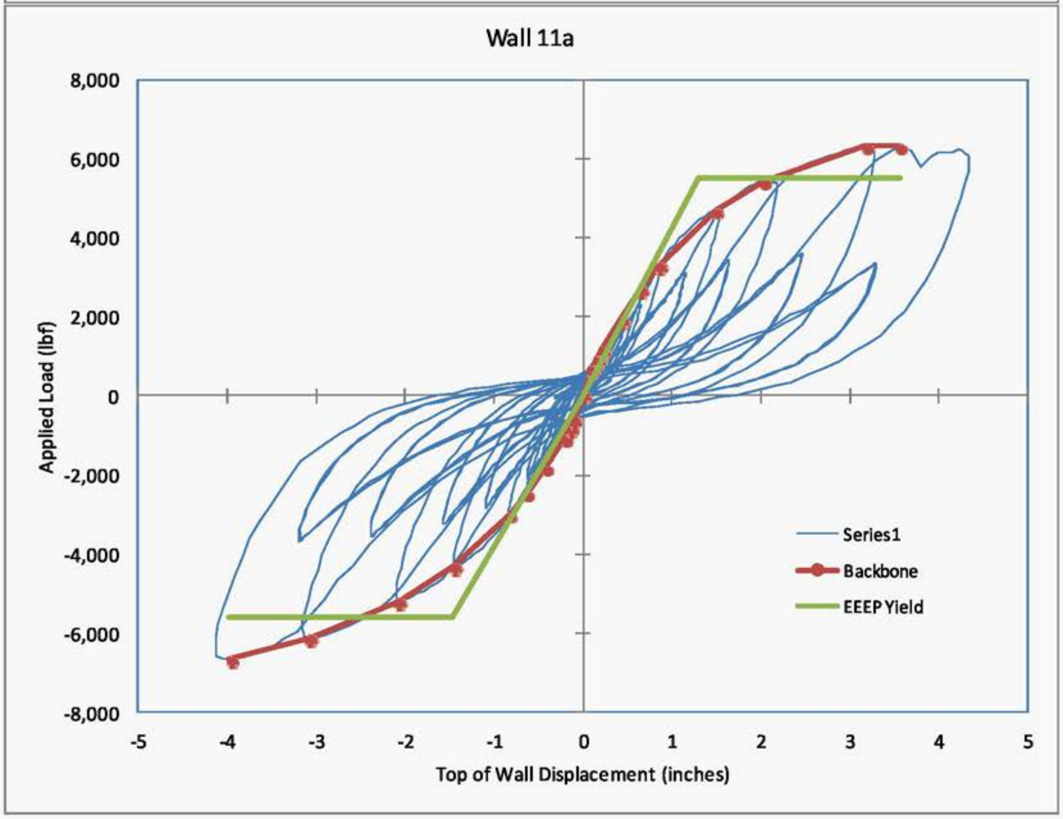
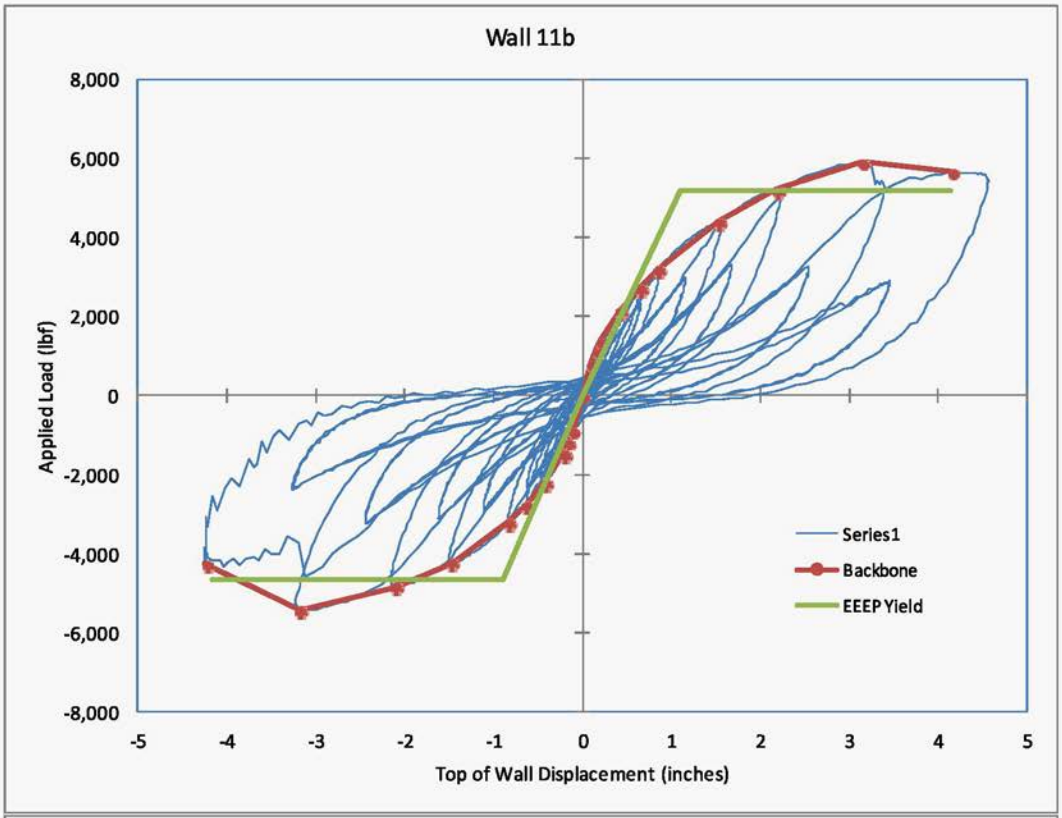
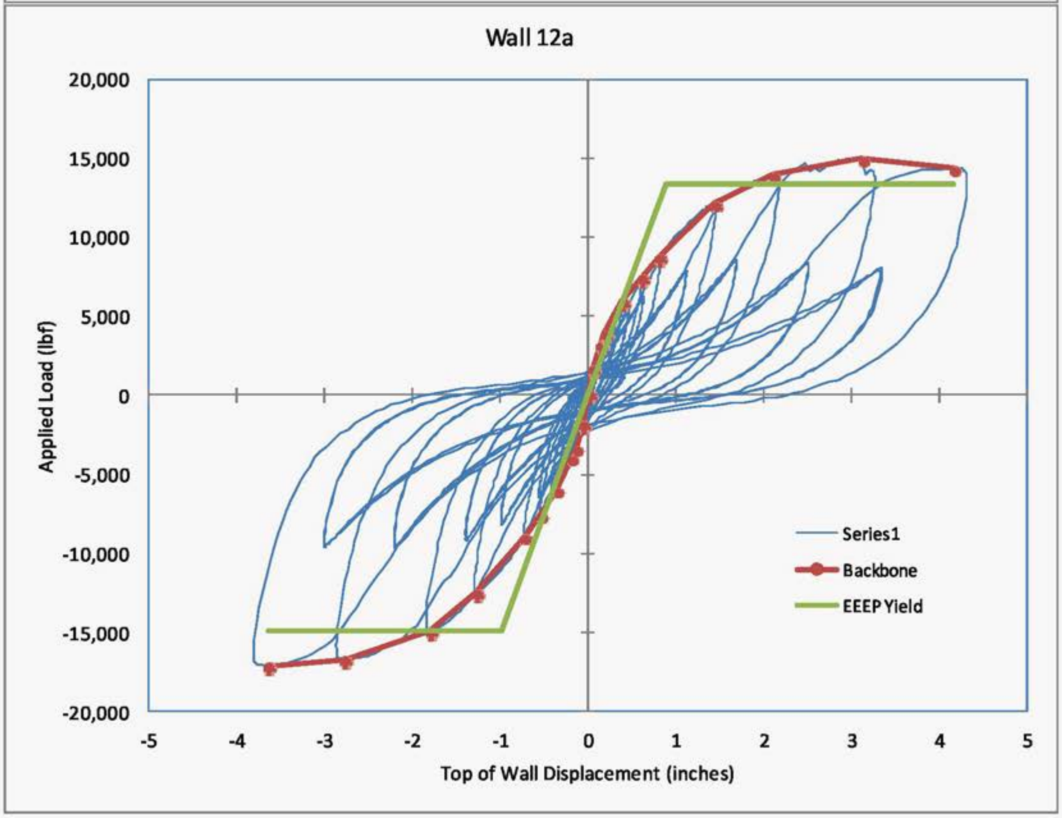
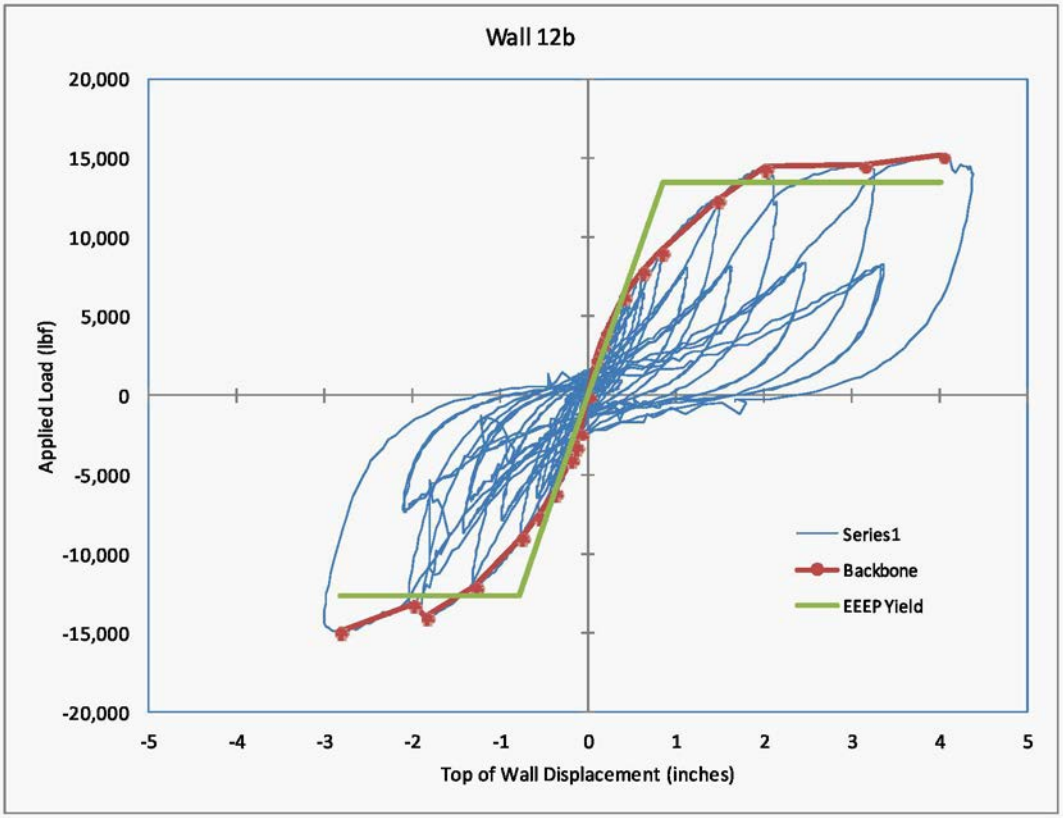
-10,000
-5
-4
-3
-2
-1
0
1
2
3
4
5
Top of Wall Displacement (inches)
Series1
Backbone
EEEP Yield


Wall 11a
Applied Load (lbf)
8,000
6,000
4,000
2,000
0
-2,000
-4,000
-6,000
-8,000
-5
-4
-3
-2
-1
0
1
2
3
4
5
Top of Wall Displacement (inches)
Series1
Backbone
EEEP Yield


Wall 11b
Applied Load (lbf)
8,000
6,000
4,000
2,000
0
-2,000
-4,000
-6,000
-8,000
-5
-4
-3
-2
-1
0
1
2
3
4
5
Top of Wall Displacement (inches)
Series1
Backbone
EEEP Yield


Wall 12a
Applied Load (lbf)
20,000
15,000
10,000
5,000
0
-5,000
-10,000
-15,000
-20,000
-5
-4
-3
-2
-1
0
1
2
3
4
5
Top of Wall Displacement (inches)
Series1
Backbone
EEEP Yield


Wall 12b
20,000
15,000
10,000
5,000
0
-5,000
-10,000
-15,000
-20,000
Applied Load (lbf)
-5
-4
-3
-2
-1
0
1
2
3
4
5
Top of Wall Displacement (inches)
Series1
Backbone
EEEP Yield

Specimen 1a	For total length		Specimen 1a	Per unit length	
	CUREE cyclic test			CUREE cyclic test	
Effective wall length	96in.	2.44m	Effective wall length	96in.	2.44m
Date:	Time:		Date:	Time:	
EEEP Parameters	units	initial	EEEP Parameters	units	initial
Peak load, F_{peak}	Kips	5.421	Peak unit load, v_{peak}	Kip/ft.	0.678
	KN	24.111		KN/m	9.888
Drift at peak load, Δ_{peak}	in.	3.409	Drift at capacity, Δ_{peak}	in.	3.409
	mm	86.59		mm	86.59
Yield load, F_{yield}	Kips	5.042	Yield unit load, v_{yield}	Kip/ft.	0.630
	KN	22.428		KN/m	9.198
Drift at yield load, Δ_{yield}	in.	1.935	Drift at yield load, Δ_{yield}	in.	1.935
	mm	49.16		mm	49.16
Proportional limit, $0.4F_{peak}$	Kips	2.168	Proportional limit, $0.4v_{peak}$	Kip/ft.	0.271
	KN	9.644		KN/m	3.955
Drift at prop. limit, $\Delta@0.4F_{peak}$	in.	0.832	Drift at prop. limit, $\Delta@0.4v_{peak}$	in.	0.832
	mm	21.14		mm	21.14
Failure load or $0.8F_{peak}$	Kips	4.336	Unit load at failure or $0.8v_{peak}$	Kip/ft.	0.542
	KN	19.288		KN/m	7.910
Drift at failure, $\Delta_{failure}$	in.	3.254	Drift at failure, $\Delta_{failure}$	in.	3.254
	mm	82.66		mm	82.66
Elastic stiffness, K_e @$0.4F_{peak}$	Kip/in.	2.605	Shear modulus, G @$0.4F_{peak}$	Kip/in.	2.605
	KN/mm	0.456		KN/mm	0.456
Work until failure	Kip·ft.	6.497	Work until failure per unit length	Kip·ft./ft.	0.812
	KN·m	8.808		KN·m/m	3.612
Load @ .32 in. (8.13 mm)	Kips	1.018	Unit load @ .32 in. (8.13 mm)	Kips/ft	0.127
	KN	4.528		KN/m	1.857
Load @ .48 in. (12.19 mm)	Kips	1.399	Unit load @ .48 in. (12.19 mm)	Kips/ft	0.175
	KN	6.223		KN/m	2.552
Load @ .96 in. (24.38 mm)	Kips	2.449	Unit load @ .96 in. (24.38 mm)	Kips/ft	0.306
	KN	10.895		KN/m	4.468
Load @ 1.6 in. (40.64 mm)	Kips	3.768	Unit load @ 1.6 in. (40.64 mm)	Kips/ft	0.471
	KN	16.762		KN/m	6.874
Ductility factor, μ		1.68	ζ_{eq} @v_{peak}		0.143

		initial	
EEEP Parameters	units	negative	positive
F_{yield}	Kips	-5.214	4.870
	KN	-23.193	21.662
v_{yield}	Kips/ft	-0.652	0.609
	KN/m	-9.512	8.884
Δ_{yield}	in.	-1.991	1.879
	mm	-50.57	47.74
$\Delta_{failure}$	in.	-3.904	4.045
	mm	-99.16	102.75

Ultimate parameters		units	negative	positive	average
SLS	F_{SLS}	Kips	-5.366	5.475	5.421
		KN	-23.868	24.355	24.112

Specimen 1a		For total length	
		CUREE cyclic test	
Effective wall length		96in.	2.44m

cycle	avg. displacement		avg. load		work per cycle		cumulative work		cyclic stiffness		damping ratio	line number
initial	in.	mm	Kips	KN	Kip·ft.	KN·m	Kip·ft.	KN·m	Kip/in.	KN/mm		
	0	0	0	0	0	0	0	0				13
1	0.092	2.329	0.415	1.846	0.003	0.005	0.003	0.005	4.526	0.793	0.170	96
7	0.142	3.608	0.578	2.570	0.006	0.008	0.026	0.035	4.063	0.711	0.140	698
14	0.193	4.910	0.708	3.149	0.009	0.013	0.058	0.079	3.651	0.639	0.129	1398
21	0.403	10.235	1.223	5.440	0.032	0.043	0.124	0.168	3.032	0.531	0.123	2097
25	0.614	15.601	1.701	7.565	0.062	0.085	0.233	0.315	2.768	0.485	0.114	2497
29	0.825	20.960	2.153	9.575	0.098	0.133	0.416	0.564	2.609	0.457	0.106	2897
32	1.452	36.887	3.524	15.676	0.309	0.418	0.811	1.100	2.428	0.425	0.115	3197
35	2.060	52.319	4.514	20.076	0.555	0.753	1.583	2.147	2.192	0.384	0.114	3497
38	2.912	73.956	5.290	23.532	1.196	1.621	3.168	4.295	1.822	0.319	0.148	3797
41	3.974	100.951	5.333	23.720	1.527	2.070	5.428	7.359	1.342	0.235	0.138	4098
44	0.303	7.689	0.247	1.099	0.007	0.010	6.497	8.808	0.696	0.122	0.176	4409

cycle	Negative stroke		Positive stroke		Negative stroke		Positive stroke		Area, Kip-in.		Unit load, KN/m	
initial	in.	Kips	in.	Kips	mm	KN	mm	KN	negative	positive	negative	positive
	0	0	0	0	0	0	0	0	0	0	0	0
1	-0.091	-0.414	0.092	0.416	-2.314	-1.840	2.344	1.852	0.019	0.019	-0.755	0.760
7	-0.140	-0.529	0.144	0.627	-3.551	-2.351	3.665	2.788	0.023	0.027	-0.964	1.143
14	-0.185	-0.626	0.201	0.790	-4.709	-2.785	5.110	3.513	0.026	0.040	-1.142	1.441
21	-0.397	-1.108	0.409	1.338	-10.086	-4.930	10.384	5.949	0.184	0.221	-2.022	2.440
25	-0.604	-1.631	0.624	1.770	-15.349	-7.255	15.852	7.875	0.284	0.335	-2.975	3.229
29	-0.813	-2.132	0.837	2.173	-20.663	-9.484	21.257	9.667	0.394	0.420	-3.889	3.964
32	-1.436	-3.587	1.469	3.461	-36.467	-15.957	37.308	15.394	1.779	1.780	-6.544	6.313
35	-2.039	-4.696	2.081	4.331	-51.788	-20.889	52.850	19.264	2.498	2.384	-8.567	7.900
38	-2.773	-5.366	3.051	5.215	-70.427	-23.867	77.485	23.196	3.692	4.629	-9.788	9.513
41	-3.904	-5.190	4.045	5.475	-99.157	-23.086	102.746	24.354	5.970	5.316	-9.468	9.988
44	-0.274	0.015	0.332	0.480	-6.949	0.066	8.428	2.133	-9.394	-11.056	0.027	0.875

Specimen 1b	For total length		Specimen 1b	Per unit length	
	CUREE cyclic test			CUREE cyclic test	
Effective wall length	96in.	2.44m	Effective wall length	96in.	2.44m
Date:	Time:		Date:	Time:	
EEEP Parameters	units	initial	EEEP Parameters	units	initial
Peak load, F_{peak}	Kips	5.837	Peak unit load, v_{peak}	Kip/ft.	0.730
	KN	25.965		KN/m	10.648
Drift at peak load, Δ_{peak}	in.	4.068	Drift at capacity, Δ_{peak}	in.	4.068
	mm	103.33		mm	103.33
Yield load, F_{yield}	Kips	5.496	Yield unit load, v_{yield}	Kip/ft.	0.687
	KN	24.448		KN/m	10.026
Drift at yield load, Δ_{yield}	in.	2.436	Drift at yield load, Δ_{yield}	in.	2.436
	mm	61.88		mm	61.88
Proportional limit, $0.4F_{peak}$	Kips	2.335	Proportional limit, $0.4v_{peak}$	Kip/ft.	0.292
	KN	10.386		KN/m	4.259
Drift at prop. limit, $\Delta@0.4F_{peak}$	in.	1.038	Drift at prop. limit, $\Delta@0.4v_{peak}$	in.	1.038
	mm	26.35		mm	26.35
Failure load or $0.8F_{peak}$	Kips	4.670	Unit load at failure or $0.8v_{peak}$	Kip/ft.	0.584
	KN	20.772		KN/m	8.519
Drift at failure, $\Delta_{failure}$	in.	3.275	Drift at failure, $\Delta_{failure}$	in.	3.275
	mm	83.19		mm	83.19
Elastic stiffness, K_e $@0.4F_{peak}$	Kip/in.	2.251	Shear modulus, G $@0.4F_{peak}$	Kip/in.	2.251
	KN/mm	0.394		KN/mm	0.394
Work until failure	Kip·ft.	7.106	Work until failure per unit length	Kip·ft./ft.	0.888
	KN·m	9.634		KN·m/m	3.951
Load @ .32 in. (8.13 mm)	Kips	0.831	Unit load @ .32 in. (8.13 mm)	Kips/ft.	0.104
	KN	3.697		KN/m	1.516
Load @ .48 in. (12.19 mm)	Kips	1.135	Unit load @ .48 in. (12.19 mm)	Kips/ft.	0.142
	KN	5.049		KN/m	2.071
Load @ .96 in. (24.38 mm)	Kips	2.155	Unit load @ .96 in. (24.38 mm)	Kips/ft	0.269
	KN	9.585		KN/m	3.931
Load @ 1.6 in. (40.64 mm)	Kips	3.642	Unit load @ 1.6 in. (40.64 mm)	Kips/ft	0.455
	KN	16.198		KN/m	6.643
Ductility factor, μ		1.36	ζ_{eq} $@v_{peak}$		0.142

		initial	
EEEP Parameters	units	negative	positive
F_{yield}	Kips	-4.861	6.132
	KN	-21.622	27.275
v_{yield}	Kips/ft.	-0.608	0.766
	KN/m	-8.867	11.185
Δ_{yield}	in.	-2.214	2.658
	mm	-56.24	67.52
$\Delta_{failure}$	in.	-4.072	4.064
	mm	-103.43	103.23

Ultimate parameters		units	negative	positive	average
SLS	F_{SLS}	Kips	-5.767	5.908	5.837
		KN	-25.653	26.278	25.966

Specimen 1b	For total length	
	CUREE cyclic test	
Effective wall length	96in.	2.44m

cycle	avg. displacement		avg. load		work per cycle		cumulative work		cyclic stiffness		damping	line
initial	in.	mm	Kips	KN	Kip·ft.	KN·m	Kip·ft.	KN·m	Kip/in.	KN/mm	ratio	number
	0	0	0	0	0	0	0	0				13
1	0.102	2.595	0.361	1.604	0.002	0.003	0.002	0.003	3.534	0.619	0.114	103
7	0.157	3.980	0.497	2.213	0.004	0.006	0.016	0.022	3.178	0.557	0.100	705
14	0.210	5.333	0.620	2.760	0.007	0.010	0.039	0.052	2.954	0.517	0.107	1405
21	0.429	10.895	1.040	4.625	0.028	0.038	0.091	0.124	2.425	0.425	0.120	2105
25	0.645	16.389	1.444	6.424	0.057	0.078	0.192	0.260	2.239	0.392	0.118	2505
29	0.859	21.821	1.909	8.493	0.093	0.126	0.374	0.508	2.223	0.389	0.109	2905
32	1.508	38.307	3.499	15.563	0.284	0.385	0.755	1.024	2.319	0.406	0.103	3205
35	2.138	54.314	4.479	19.925	0.591	0.801	1.601	2.170	2.095	0.367	0.118	3505
38	3.179	80.758	5.498	24.455	1.263	1.713	3.317	4.497	1.729	0.303	0.138	3805
41	4.068	103.328	5.837	25.965	1.772	2.402	5.934	8.045	1.435	0.251	0.142	4106
44	0.311	7.904	0.298	1.327	0.011	0.014	7.106	9.634	0.970	0.170	0.220	4424

cycle	Negative stroke		Positive stroke		Negative stroke		Positive stroke		Area, Kip-in.		Unit load, KN/m	
initial	in.	Kips	in.	Kips	mm	KN	mm	KN	negative	positive	negative	positive
	0	0	0	0	0	0	0	0	0	0	0	0
1	-0.102	-0.491	0.102	0.230	-2.586	-2.184	2.603	1.023	0.025	0.012	-0.896	0.420
7	-0.156	-0.662	0.157	0.333	-3.967	-2.945	3.993	1.481	0.031	0.015	-1.208	0.607
14	-0.210	-0.790	0.210	0.451	-5.339	-3.513	5.326	2.007	0.039	0.021	-1.441	0.823
21	-0.428	-1.207	0.430	0.873	-10.859	-5.367	10.932	3.882	0.217	0.146	-2.201	1.592
25	-0.643	-1.607	0.647	1.281	-16.345	-7.150	16.434	5.697	0.304	0.233	-2.932	2.336
29	-0.857	-1.978	0.861	1.841	-21.773	-8.798	21.869	8.187	0.383	0.334	-3.608	3.358
32	-1.505	-3.079	1.511	3.918	-38.235	-13.696	38.379	17.429	1.639	1.872	-5.617	7.148
35	-2.135	-4.027	2.141	4.932	-54.237	-17.912	54.392	21.937	2.238	2.790	-7.346	8.996
38	-3.177	-5.274	3.182	5.722	-80.688	-23.457	80.828	25.453	4.843	5.544	-9.620	10.438
41	-4.072	-5.767	4.064	5.908	-103.431	-25.652	103.226	26.277	4.943	5.128	-10.520	10.776
44	-0.315	-0.046	0.307	0.550	-8.014	-0.206	7.795	2.447	-10.919	-12.131	-0.084	1.004

Specimen 2a	For total length		Specimen 2a	Per unit length	
	CUREE cyclic test			CUREE cyclic test	
Effective wall length	96in.	2.44m	Effective wall length	96in.	2.44m
Date:	Time:		Date:	Time:	
EEEP Parameters	units	initial	EEEP Parameters	units	initial
Peak load, F_{peak}	Kips	7.296	Peak unit load, v_{peak}	Kip/ft.	0.912
	KN	32.450		KN/m	13.308
Drift at peak load, Δ_{peak}	in.	1.280	Drift at capacity, Δ_{peak}	in.	1.280
	mm	32.52		mm	32.52
Yield load, F_{yield}	Kips	6.214	Yield unit load, v_{yield}	Kip/ft.	0.777
	KN	27.641		KN/m	11.336
Drift at yield load, Δ_{yield}	in.	0.770	Drift at yield load, Δ_{yield}	in.	0.770
	mm	19.55		mm	19.55
Proportional limit, $0.4F_{peak}$	Kips	2.918	Proportional limit, $0.4v_{peak}$	Kip/ft.	0.365
	KN	12.980		KN/m	5.323
Drift at prop. limit, $\Delta@0.4F_{peak}$	in.	0.362	Drift at prop. limit, $\Delta@0.4v_{peak}$	in.	0.362
	mm	9.19		mm	9.19
Failure load or $0.8F_{peak}$	Kips	5.836	Unit load at failure or $0.8v_{peak}$	Kip/ft.	0.730
	KN	25.960		KN/m	10.646
Drift at failure, $\Delta_{failure}$	in.	2.455	Drift at failure, $\Delta_{failure}$	in.	2.455
	mm	62.36		mm	62.36
Elastic stiffness, K_e $@0.4F_{peak}$	Kip/in.	8.110	Shear modulus, G $@0.4F_{peak}$	Kip/in.	8.110
	KN/mm	1.420		KN/mm	1.420
Work until failure	Kip·ft.	3.315	Work until failure per unit length	Kip·ft./ft.	0.414
	KN·m	4.495		KN·m/m	1.843
Load @ .32 in. (8.13 mm)	Kips	2.676	Unit load @ .32 in. (8.13 mm)	Kips/ft.	0.335
	KN	11.904		KN/m	4.882
Load @ .48 in. (12.19 mm)	Kips	3.638	Unit load @ .48 in. (12.19 mm)	Kips/ft.	0.455
	KN	16.184		KN/m	6.637
Load @ .96 in. (24.38 mm)	Kips	5.964	Unit load @ .96 in. (24.38 mm)	Kips/ft.	0.745
	KN	26.526		KN/m	10.879
Load @ 1.6 in. (40.64 mm)	Kips	6.643	Unit load @ 1.6 in. (40.64 mm)	Kips/ft.	0.830
	KN	29.548		KN/m	12.118
Ductility factor, μ		3.22	ζ_{eq} $@v_{peak}$		0.140

		initial	
EEEP Parameters	units	negative	positive
F_{yield}	Kips	-6.464	5.964
	KN	-28.754	26.528
v_{yield}	Kips/ft.	-0.808	0.746
	KN/m	-11.792	10.879
Δ_{yield}	in.	-0.733	0.807
	mm	-18.61	20.49
$\Delta_{failure}$	in.	-2.872	2.039
	mm	-72.94	51.79

Ultimate parameters		units	negative	positive	average
SLS	F_{SLS}	Kips	-7.479	7.112	7.296
		KN	-33.269	31.635	32.452

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

cycle	avg. displacement		avg. load		work per cycle		cumulative work		cyclic stiffness		damping	line
initial	in.	mm	Kips	KN	Kip·ft.	KN·m	Kip·ft.	KN·m	Kip/in.	KN/mm	ratio	number
	0	0	0	0	0	0	0	0				13
1	0.097	2.451	1.168	5.196	0.006	0.008	0.006	0.008	12.537	2.195	0.097	101
7	0.149	3.797	1.555	6.917	0.012	0.016	0.044	0.059	10.445	1.829	0.096	703
14	0.198	5.034	1.919	8.535	0.019	0.026	0.101	0.137	9.708	1.700	0.095	1402
21	0.403	10.237	3.237	14.398	0.074	0.100	0.238	0.323	7.998	1.401	0.108	2101
25	0.612	15.551	4.427	19.692	0.141	0.191	0.485	0.657	7.193	1.260	0.098	2501
29	0.818	20.780	5.386	23.958	0.217	0.294	0.904	1.226	6.555	1.148	0.093	2900
32	1.280	32.522	7.296	32.450	0.682	0.925	1.796	2.435	5.752	1.007	0.140	3200
35	1.559	39.596	6.647	29.564	1.046	1.419	3.315	4.495	4.305	0.754	0.193	3501
38	2.658	67.511	5.865	26.085	1.530	2.074	5.531	7.499	2.215	0.388	0.187	3801
41	3.729	94.728	4.764	21.191	1.755	2.379	8.270	11.212	1.287	0.225	0.190	4101
44	3.315	84.204	4.722	21.002	0.682	0.924	20.668	28.021	1.420	0.249	0.083	4320
47	2.436	61.883	4.525	20.127	0.873	1.184	11.620	15.754	1.863	0.326	0.152	7545
50	3.228	81.980	3.282	14.597	0.818	1.109	15.975	21.658	1.019	0.178	0.148	8146

cycle	Negative stroke		Positive stroke		Negative stroke		Positive stroke		Area, Kip-in.		Unit load, KN/m	
initial	in.	Kips	in.	Kips	mm	KN	mm	KN	negative	positive	negative	positive
	0	0	0	0	0	0	0	0	0	0	0	0
1	-0.120	-1.290	0.073	1.046	-3.045	-5.740	1.857	4.653	0.077	0.038	-2.354	1.908
7	-0.170	-1.723	0.129	1.387	-4.318	-7.665	3.277	6.170	0.075	0.068	-3.143	2.530
14	-0.224	-2.125	0.173	1.713	-5.679	-9.452	4.389	7.619	0.103	0.068	-3.876	3.125
21	-0.427	-3.653	0.379	2.821	-10.846	-16.247	9.629	12.549	0.588	0.468	-6.663	5.146
25	-0.638	-5.161	0.587	3.693	-16.200	-22.956	14.902	16.428	0.929	0.676	-9.414	6.737
29	-0.842	-6.337	0.794	4.435	-21.394	-28.188	20.165	19.727	1.176	0.842	-11.560	8.090
32	-1.171	-7.479	1.390	7.112	-29.741	-33.267	35.303	31.633	2.270	3.441	-13.643	12.973
35	-1.691	-6.456	2.069	5.624	-42.941	-28.717	52.545	25.016	3.621	4.323	-11.777	10.259
38	-2.856	-6.007	2.459	5.722	-72.555	-26.721	62.466	25.450	7.266	2.216	-10.958	10.437
41	-3.914	-4.308	3.545	5.220	-99.423	-19.163	90.033	23.219	5.456	5.937	-7.859	9.522

Specimen 2b	For total length		Specimen 2b	Per unit length	
	CUREE cyclic test			CUREE cyclic test	
Effective wall length	96in.	2.44m	Effective wall length	96in.	2.44m
Date:	Time:		Date:	Time:	
EEEP Parameters	units	initial	EEEP Parameters	units	initial
Peak load, F_{peak}	Kips	6.614	Peak unit load, v_{peak}	Kip/ft.	0.827
	KN	29.420		KN/m	12.065
Drift at peak load, Δ_{peak}	in.	1.112	Drift at capacity, Δ_{peak}	in.	1.112
	mm	28.24		mm	28.24
Yield load, F_{yield}	Kips	5.808	Yield unit load, v_{yield}	Kip/ft.	0.726
	KN	25.835		KN/m	10.595
Drift at yield load, Δ_{yield}	in.	0.602	Drift at yield load, Δ_{yield}	in.	0.602
	mm	15.29		mm	15.29
Proportional limit, $0.4F_{peak}$	Kips	2.646	Proportional limit, $0.4v_{peak}$	Kip/ft.	0.331
	KN	11.768		KN/m	4.826
Drift at prop. limit, $\Delta@0.4F_{peak}$	in.	0.274	Drift at prop. limit, $\Delta@0.4v_{peak}$	in.	0.274
	mm	6.97		mm	6.97
Failure load or $0.8F_{peak}$	Kips	5.361	Unit load at failure or $0.8v_{peak}$	Kip/ft.	0.670
	KN	23.845		KN/m	9.779
Drift at failure, $\Delta_{failure}$	in.	2.480	Drift at failure, $\Delta_{failure}$	in.	2.480
	mm	62.98		mm	62.98
Elastic stiffness, K_e @$0.4F_{peak}$	Kip/in.	9.717	Shear modulus, G @$0.4F_{peak}$	Kip/in	9.717
	KN/mm	1.702		KN/mm	1.702
Work until failure	Kip·ft.	5.527	Work until failure per unit length	Kip·ft./ft.	0.691
	KN·m	7.493		KN·m/m	3.073
Load @ .32 in. (8.13 mm)	Kips	3.012	Unit load @ .32 in. (8.13 mm)	Kips/ft.	0.376
	KN	13.397		KN/m	5.494
Load @ .48 in. (12.19 mm)	Kips	4.173	Unit load @ .48 in. (12.19 mm)	Kips/ft.	0.522
	KN	18.560		KN/m	7.612
Load @ .96 in. (24.38 mm)	Kips	5.921	Unit load @ .96 in. (24.38 mm)	Kips/ft.	0.740
	KN	26.338		KN/m	10.801
Load @ 1.6 in. (40.64 mm)	Kips	6.104	Unit load @ 1.6 in. (40.64 mm)	Kips/ft.	0.763
	KN	27.151		KN/m	11.135
Ductility factor, μ		4.30	ζ_{eq} @v_{peak}		0.142

		initial	
EEEP Parameters	units	negative	positive
F_{yield}	Kips	-5.033	6.583
	KN	-22.388	29.282
v_{yield}	Kips/ft.	-0.629	0.823
	KN/m	-9.182	12.008
Δ_{yield}	in.	-0.498	0.707
	mm	-12.64	17.95
$\Delta_{failure}$	in.	-2.649	2.310
	mm	-67.28	58.68

Ultimate parameters		units	negative	positive	average
SLS	F_{SLS}	Kips	-6.316	7.534	6.925
		KN	-28.093	33.511	30.802

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

cycle	avg. displacement		avg. load		work per cycle		cumulative work		cyclic stiffness		damping	line
initial	in.	mm	Kips	KN	Kip·ft.	KN·m	Kip·ft.	KN·m	Kip/in.	KN/mm	ratio	number
	0	0	0	0	0	0	0	0				13
1	0.097	2.460	1.238	5.509	0.008	0.011	0.008	0.011	12.787	2.239	0.130	197
7	0.152	3.865	1.658	7.375	0.014	0.019	0.057	0.078	10.897	1.908	0.106	1401
14	0.204	5.194	2.064	9.180	0.023	0.031	0.130	0.176	10.095	1.768	0.102	2801
21	0.407	10.344	3.728	16.583	0.082	0.111	0.288	0.391	9.155	1.603	0.103	4201
25	0.613	15.566	4.987	22.184	0.164	0.222	0.568	0.771	8.137	1.425	0.102	5001
29	0.816	20.716	5.860	26.065	0.256	0.347	1.050	1.423	7.185	1.258	0.102	5801
32	1.220	30.988	6.925	30.800	0.817	1.108	2.104	2.852	5.765	1.009	0.182	6401
35	1.825	46.364	5.843	25.990	0.974	1.320	3.538	4.797	3.191	0.559	0.174	7001
38	2.475	62.868	5.194	23.103	1.411	1.913	5.527	7.493	2.123	0.372	0.211	7601
41	2.431	61.739	3.544	15.765	0.479	0.650	6.516	8.834	1.458	0.255	0.106	3999
44	3.322	84.367	2.176	9.681	0.399	0.541	9.160	12.418	0.654	0.115	0.105	4319

cycle	Negative stroke		Positive stroke		Negative stroke		Positive stroke		Area, Kip-in.		Unit load, KN/m	
initial	in.	Kips	in.	Kips	mm	KN	mm	KN	negative	positive	negative	positive
	0	0	0	0	0	0	0	0	0	0	0	0
1	-0.097	-1.280	0.097	1.197	-2.461	-5.694	2.459	5.323	0.062	0.058	-2.335	2.183
7	-0.152	-1.669	0.152	1.647	-3.866	-7.426	3.863	7.324	0.082	0.079	-3.045	3.004
14	-0.202	-2.095	0.207	2.033	-5.141	-9.320	5.248	9.041	0.094	0.100	-3.822	3.708
21	-0.408	-3.749	0.406	3.707	-10.373	-16.677	10.315	16.490	0.602	0.573	-6.839	6.763
25	-0.601	-4.864	0.625	5.111	-15.258	-21.636	15.875	22.733	0.828	0.965	-8.873	9.323
29	-0.791	-5.695	0.840	6.025	-20.089	-25.332	21.344	26.798	1.004	1.199	-10.389	10.990
32	-1.465	-4.971	1.433	7.534	-37.203	-22.111	36.401	33.509	3.593	4.019	-9.068	13.742
35	-1.767	-5.056	1.884	6.631	-44.879	-22.487	47.849	29.494	1.515	3.192	-9.222	12.096
38	-2.649	-4.695	3.348	4.557	-67.280	-20.884	85.032	20.271	4.300	8.189	-8.564	8.313

Specimen 3a	For total length	
	CUREE cyclic test	
Effective wall length	96in.	2.44m
Date:	Time:	
EEEP Parameters	units	initial
Peak load, F_{peak}	Kips	10.370
	KN	46.125
Drift at peak load, Δ_{peak}	in.	2.126
	mm	54.00
Yield load, F_{yield}	Kips	9.554
	KN	42.494
Drift at yield load, Δ_{yield}	in.	0.885
	mm	22.47
Proportional limit, $0.4F_{peak}$	Kips	4.148
	KN	18.450
Drift at prop. limit, $\Delta@0.4F_{peak}$	in.	0.384
	mm	9.75
Failure load or $0.8F_{peak}$	Kips	9.036
	KN	40.192
Drift at failure, $\Delta_{failure}$	in.	3.327
	mm	84.51
Elastic stiffness, K_e $@0.4F_{peak}$	Kip/in.	10.824
	KN/mm	1.895
Work until failure	Kip·ft.	12.369
	KN·m	16.769
Load @ .32 in. (8.13 mm)	Kips	3.642
	KN	16.198
Load @ .48 in. (12.19 mm)	Kips	4.926
	KN	21.910
Load @ .96 in. (24.38 mm)	Kips	8.168
	KN	36.333
Load @ 1.6 in. (40.64 mm)	Kips	10.101
	KN	44.930
Ductility factor, μ		3.77

Specimen 3a	Per unit length	
	CUREE cyclic test	
Effective wall length	96in.	2.44m
Date:	Time:	
EEEP Parameters	units	initial
Peak unit load, v_{peak}	Kip/ft.	1.296
	KN/m	18.916
Drift at capacity, Δ_{peak}	in.	2.126
	mm	54.00
Yield unit load, v_{yield}	Kip/ft.	1.194
	KN/m	17.427
Drift at yield load, Δ_{yield}	in.	0.885
	mm	22.47
Proportional limit, $0.4v_{peak}$	Kip/ft.	0.518
	KN/m	7.566
Drift at prop. limit, $\Delta@0.4v_{peak}$	in.	0.384
	mm	9.75
Unit load at failure or $0.8v_{peak}$	Kip/ft.	1.130
	KN/m	16.483
Drift at failure, $\Delta_{failure}$	in.	3.327
	mm	84.51
Shear modulus, G $@0.4F_{peak}$	Kip/in.	10.824
	KN/mm	1.895
Work until failure per unit length	Kip·ft./ft.	1.546
	KN·m/m	6.877
Unit load @ .32 in. (8.13 mm)	Kips/ft.	0.455
	KN/m	6.643
Unit load @ .48 in. (12.19 mm)	Kips/ft.	0.616
	KN/m	8.985
Unit load @ .96 in. (24.38 mm)	Kips/ft.	1.021
	KN/m	14.900
Unit load @ 1.6 in. (40.64 mm)	Kips/ft.	1.263
	KN/m	18.426
ζ_{eq} @v_{peak}		0.160

		initial	
EEEP Parameters	units	negative	positive
F_{yield}	Kips	-8.913	10.194
	KN	-39.646	45.343
v_{yield}	Kips/ft.	-1.114	1.274
	KN/m	-16.259	18.595
Δ_{yield}	in.	-0.804	0.965
	mm	-20.42	24.51
$\Delta_{failure}$	in.	-3.072	3.582
	mm	-78.04	90.98

Ultimate parameters		units	negative	positive	average
SLS	F_{SLS}	Kips	-9.712	11.028	10.370
		KN	-43.199	49.055	46.127

Specimen 3a		For total length	
		CUREE cyclic test	
Effective wall length		96in.	2.44m

cycle	avg. displacement		avg. load		work per cycle		cumulative work		cyclic stiffness		damping	line
initial	in.	mm	Kips	KN	Kip·ft.	KN·m	Kip·ft.	KN·m	Kip/in.	KN/mm	ratio	number
	0	0	0	0	0	0	0	0				13
1	0.096	2.441	1.535	6.827	0.008	0.011	0.008	0.011	16.536	2.896	0.107	102
7	0.148	3.758	2.111	9.389	0.017	0.023	0.063	0.086	14.467	2.533	0.103	704
14	0.199	5.044	2.620	11.652	0.028	0.038	0.148	0.200	13.288	2.327	0.103	1403
21	0.401	10.188	4.343	19.320	0.100	0.135	0.341	0.462	10.828	1.896	0.109	2102
25	0.603	15.325	5.845	26.001	0.184	0.250	0.671	0.910	9.687	1.696	0.100	2501
29	0.808	20.524	7.355	32.716	0.284	0.385	1.222	1.657	9.102	1.594	0.091	2901
32	1.345	34.172	10.256	45.620	0.967	1.312	2.468	3.346	7.622	1.335	0.134	3201
35	1.741	44.210	10.292	45.779	1.607	2.178	4.744	6.432	6.094	1.067	0.173	3502
38	2.679	68.042	10.121	45.017	2.675	3.626	8.439	11.441	3.786	0.663	0.187	3802
41	3.835	97.418	7.968	35.440	2.458	3.333	12.369	16.769	2.127	0.372	0.157	4102
44	3.315	84.204	4.722	21.002	0.682	0.924	20.668	28.021	1.420	0.249	0.083	4320
47	2.436	61.883	4.525	20.127	0.873	1.184	11.620	15.754	1.863	0.326	0.152	7545
50	3.228	81.980	3.282	14.597	0.818	1.109	15.975	21.658	1.019	0.178	0.148	8146

cycle	Negative stroke		Positive stroke		Negative stroke		Positive stroke		Area, Kip-in.		Unit load, KN/m	
initial	in.	Kips	in.	Kips	mm	KN	mm	KN	negative	positive	negative	positive
	0	0	0	0	0	0	0	0	0	0	0	0
1	-0.114	-1.546	0.078	1.524	-2.901	-6.876	1.981	6.778	0.088	0.059	-2.820	2.780
7	-0.164	-2.060	0.132	2.162	-4.158	-9.161	3.358	9.616	0.089	0.100	-3.757	3.944
14	-0.214	-2.590	0.183	2.649	-5.448	-11.521	4.641	11.783	0.118	0.121	-4.725	4.832
21	-0.410	-4.452	0.392	4.235	-10.414	-19.802	9.962	18.838	0.688	0.721	-8.121	7.725
25	-0.607	-6.022	0.599	5.669	-15.428	-26.784	15.222	25.217	1.034	1.026	-10.984	10.342
29	-0.812	-7.421	0.805	7.289	-20.612	-33.008	20.437	32.423	1.372	1.330	-13.537	13.297
32	-1.280	-9.712	1.411	10.801	-32.515	-43.197	35.829	48.043	4.014	5.481	-17.715	19.703
35	-1.987	-9.584	2.096	9.887	-50.482	-42.628	53.238	43.979	6.825	7.090	-17.482	18.036
38	-2.385	-9.213	2.972	11.028	-60.589	-40.981	75.494	49.053	3.740	9.163	-16.806	20.117
41	-4.089	-5.633	3.582	10.303	-103.856	-25.054	90.980	45.827	12.644	6.503	-10.275	18.794

Specimen 3b	For total length		Specimen 3b	Per unit length	
	CUREE cyclic test			CUREE cyclic test	
Effective wall length	96in.	2.44m	Effective wall length	96in.	2.44m
Date:	Time:		Date:	Time:	
EEEP Parameters	units	initial	EEEP Parameters	units	initial
Peak load, F_{peak}	Kips	8.955	Peak unit load, v_{peak}	Kip/ft.	1.119
	KN	39.832		KN/m	16.335
Drift at peak load, Δ_{peak}	in.	1.335	Drift at capacity, Δ_{peak}	in.	1.335
	mm	33.91		mm	33.91
Yield load, F_{yield}	Kips	7.541	Yield unit load, v_{yield}	Kip/ft.	0.943
	KN	33.541		KN/m	13.755
Drift at yield load, Δ_{yield}	in.	0.700	Drift at yield load, Δ_{yield}	in.	0.700
	mm	17.77		mm	17.77
Proportional limit, $0.4F_{peak}$	Kips	3.582	Proportional limit, $0.4v_{peak}$	Kip/ft.	0.448
	KN	15.933		KN/m	6.534
Drift at prop. limit, $\Delta@0.4F_{peak}$	in.	0.332	Drift at prop. limit, $\Delta@0.4v_{peak}$	in.	0.332
	mm	8.44		mm	8.44
Failure load or $0.8F_{peak}$	Kips	7.164	Unit load at failure or $0.8v_{peak}$	Kip/ft.	0.895
	KN	31.865		KN/m	13.068
Drift at failure, $\Delta_{failure}$	in.	2.353	Drift at failure, $\Delta_{failure}$	in.	2.353
	mm	59.77		mm	59.77
Elastic stiffness, K_e @$0.4F_{peak}$	Kip/in.	10.779	Shear modulus, G @$0.4F_{peak}$	Kip/in.	10.779
	KN/mm	1.888		KN/mm	1.888
Work until failure	Kip·ft.	6.359	Work until failure per unit length	Kip·ft./ft.	0.795
	KN·m	8.621		KN·m/m	3.535
Load @ .32 in. (8.13 mm)	Kips	3.476	Unit load @ .32 in. (8.13 mm)	Kips/ft.	0.435
	KN	15.462		KN/m	6.341
Load @ .48 in. (12.19 mm)	Kips	4.628	Unit load @ .48 in. (12.19 mm)	Kips/ft.	0.579
	KN	20.587		KN/m	8.443
Load @ .96 in. (24.38 mm)	Kips	7.240	Unit load @ .96 in. (24.38 mm)	Kips/ft.	0.905
	KN	32.202		KN/m	13.206
Load @ 1.6 in. (40.64 mm)	Kips	8.117	Unit load @ 1.6 in. (40.64 mm)	Kips/ft.	1.015
	KN	36.106		KN/m	14.807
Ductility factor, μ		3.32	ζ_{eq} @v_{peak}		0.168

		initial	
EEEP Parameters	units	negative	positive
F_{yield}	Kips	-7.038	8.044
	KN	-31.304	35.778
v_{yield}	Kips/ft.	-0.880	1.005
	KN/m	-12.838	14.673
Δ_{yield}	in.	-0.651	0.749
	mm	-16.52	19.02
$\Delta_{failure}$	in.	-1.796	2.910
	mm	-45.63	73.91

Ultimate parameters		units	negative	positive	average
SLS	F_{SLS}	Kips	-8.367	9.543	8.955
		KN	-37.219	42.448	39.833

Specimen 3b	For total length	
	CUREE cyclic test	
Effective wall length	96in.	2.44m

cycle	avg. displacement		avg. load		work per cycle		cumulative work		cyclic stiffness		damping	line
initial	in.	mm	Kips	KN	Kip·ft.	KN·m	Kip·ft.	KN·m	Kip/in.	KN/mm	ratio	number
	0	0	0	0	0	0	0	0				13
1	0.098	2.498	1.521	6.765	0.008	0.011	0.008	0.011	15.460	2.707	0.102	197
7	0.149	3.782	2.085	9.276	0.016	0.022	0.061	0.082	14.005	2.453	0.098	1400
14	0.202	5.123	2.569	11.429	0.027	0.036	0.142	0.192	12.739	2.231	0.098	2800
21	0.410	10.427	4.172	18.555	0.097	0.132	0.329	0.446	10.161	1.779	0.108	4199
25	0.614	15.593	5.519	24.550	0.183	0.248	0.653	0.885	8.984	1.573	0.103	5000
29	0.817	20.743	6.598	29.350	0.281	0.381	1.191	1.615	8.067	1.413	0.099	5800
32	1.335	33.913	8.955	39.832	1.048	1.421	2.497	3.385	6.712	1.175	0.168	6399
35	1.927	48.933	7.084	31.510	1.190	1.613	4.183	5.672	3.674	0.643	0.166	6999
38	3.043	77.287	6.273	27.902	1.532	2.077	6.359	8.621	2.046	0.358	0.152	7600
41	4.078	103.580	6.732	29.945	2.012	2.728	9.208	12.483	1.652	0.289	0.140	8201
44	3.239	82.281	3.977	17.688	0.661	0.896	13.774	18.675	1.226	0.215	0.098	4319

cycle	Negative stroke		Positive stroke		Negative stroke		Positive stroke		Area, Kip-in.		Unit load, KN/m	
initial	in.	Kips	in.	Kips	mm	KN	mm	KN	negative	positive	negative	positive
	0	0	0	0	0	0	0	0	0	0	0	0
1	-0.099	-1.571	0.097	1.471	-2.520	-6.988	2.476	6.541	0.078	0.072	-2.866	2.683
7	-0.149	-2.078	0.149	2.093	-3.777	-9.244	3.787	9.308	0.090	0.092	-3.791	3.817
14	-0.200	-2.561	0.203	2.578	-5.090	-11.393	5.156	11.465	0.120	0.126	-4.672	4.702
21	-0.408	-4.056	0.413	4.287	-10.358	-18.041	10.495	19.070	0.686	0.721	-7.399	7.821
25	-0.598	-5.212	0.630	5.826	-15.187	-23.184	15.999	25.916	0.881	1.096	-9.508	10.628
29	-0.785	-6.074	0.849	7.123	-19.926	-27.015	21.560	31.684	1.053	1.417	-11.079	12.994
32	-1.349	-8.367	1.321	9.543	-34.272	-37.217	33.553	42.446	4.078	3.935	-15.263	17.407
35	-1.911	-6.267	1.942	7.901	-48.527	-27.874	49.339	35.146	4.106	5.421	-11.431	14.413
38	-2.902	-4.987	3.183	7.559	-73.718	-22.184	80.856	33.621	5.581	9.591	-9.098	13.788
41	-4.110	-6.051	4.046	7.413	-104.394	-26.916	102.766	32.975	6.666	6.457	-11.038	13.523

Specimen 4a	For total length		Specimen 4a	Per unit length	
	CUREE cyclic test			CUREE cyclic test	
Effective wall length	96in.	2.44m	Effective wall length	96in.	2.44m
Date:	Time:		Date:	Time:	
EEEP Parameters	units	initial	EEEP Parameters	units	initial
Peak load, F_{peak}	Kips	14.932	Peak unit load, v_{peak}	Kip/ft.	1.867
	KN	66.418		KN/m	27.238
Drift at peak load, Δ_{peak}	in.	1.722	Drift at capacity, Δ_{peak}	in.	1.722
	mm	43.74		mm	43.74
Yield load, F_{yield}	Kips	12.989	Yield unit load, v_{yield}	Kip/ft.	1.624
	KN	57.774		KN/m	23.693
Drift at yield load, Δ_{yield}	in.	1.040	Drift at yield load, Δ_{yield}	in.	1.040
	mm	26.42		mm	26.42
Proportional limit, $0.4F_{peak}$	Kips	5.973	Proportional limit, $0.4v_{peak}$	Kip/ft.	0.747
	KN	26.567		KN/m	10.895
Drift at prop. limit, $\Delta@0.4F_{peak}$	in.	0.480	Drift at prop. limit, $\Delta@0.4v_{peak}$	in.	0.480
	mm	12.18		mm	12.18
Failure load or $0.8F_{peak}$	Kips	12.844	Unit load at failure or $0.8v_{peak}$	Kip/ft.	1.605
	KN	57.128		KN/m	23.429
Drift at failure, $\Delta_{failure}$	in.	2.111	Drift at failure, $\Delta_{failure}$	in.	2.111
	mm	53.63		mm	53.63
Elastic stiffness, K_e @$0.4F_{peak}$	Kip/in.	12.535	Shear modulus, G @$0.4F_{peak}$	Kip/in.	12.535
	KN/mm	2.195		KN/mm	2.195
Work until failure	Kip·ft.	8.623	Work until failure per unit length	Kip·ft./ft.	1.078
	KN·m	11.690		KN·m/m	4.794
Load @ .32 in. (8.13 mm)	Kips	4.234	Unit load @ .32 in. (8.13 mm)	Kips/ft.	0.529
	KN	18.835		KN/m	7.724
Load @ .48 in. (12.19 mm)	Kips	6.002	Unit load @ .48 in. (12.19 mm)	Kips/ft.	0.750
	KN	26.695		KN/m	10.948
Load @ .96 in. (24.38 mm)	Kips	10.231	Unit load @ .96 in. (24.38 mm)	Kips/ft.	1.279
	KN	45.507		KN/m	18.663
Load @ 1.6 in. (40.64 mm)	Kips	14.314	Unit load @ 1.6 in. (40.64 mm)	Kips/ft.	1.789
	KN	63.670		KN/m	26.111
Ductility factor, μ		2.05	ζ_{eq} @v_{peak}		0.150

		initial	
EEEP Parameters	units	negative	positive
F_{yield}	Kips	-11.927	14.050
	KN	-53.052	62.496
v_{yield}	Kips/ft.	-1.491	1.756
	KN/m	-21.757	25.630
Δ_{yield}	in.	-1.074	1.006
	mm	-27.29	25.55
$\Delta_{failure}$	in.	-1.681	2.542
	mm	-42.69	64.57

Ultimate parameters		units	negative	positive	average
SLS	F_{SLS}	Kips	-14.085	15.779	14.932
		KN	-62.653	70.190	66.421

Specimen 4a	For total length	
	CUREE cyclic test	
Effective wall length	96in.	2.44m

cycle	avg. displacement		avg. load		work per cycle		cumulative work		cyclic stiffness		damping ratio	line number
initial	in.	mm	Kips	KN	Kip·ft.	KN·m	Kip·ft.	KN·m	Kip/in.	KN/mm		
	0	0	0	0	0	0	0	0				13
1	0.098	2.483	1.528	6.795	0.008	0.010	0.008	0.010	16.598	2.907	0.098	101
7	0.148	3.757	2.179	9.690	0.016	0.021	0.054	0.073	15.124	2.648	0.095	702
14	0.198	5.020	2.854	12.696	0.027	0.036	0.126	0.171	14.710	2.576	0.092	1401
21	0.400	10.152	5.132	22.828	0.102	0.138	0.308	0.418	12.882	2.256	0.095	2100
25	0.597	15.164	7.243	32.219	0.205	0.278	0.671	0.909	12.156	2.129	0.091	2500
29	0.792	20.107	9.062	40.307	0.335	0.454	1.301	1.763	11.457	2.006	0.089	2900
32	1.386	35.198	13.191	58.673	1.131	1.533	2.747	3.725	9.519	1.667	0.118	3200
35	1.722	43.743	14.932	66.418	2.031	2.753	5.565	7.545	8.666	1.518	0.150	3500
38	2.132	54.155	11.177	49.715	1.796	2.435	8.623	11.690	5.140	0.900	0.136	3796
41	3.442	87.427	12.101	53.826	4.168	5.651	19.101	25.896	3.530	0.618	0.192	4104
44	3.315	84.204	4.722	21.002	0.682	0.924	20.668	28.021	1.420	0.249	0.083	4320
47	2.436	61.883	4.525	20.127	0.873	1.184	11.620	15.754	1.863	0.326	0.152	7545
50	3.228	81.980	3.282	14.597	0.818	1.109	15.975	21.658	1.019	0.178	0.148	8146

cycle	Negative stroke		Positive stroke		Negative stroke		Positive stroke		Area, Kip-in.		Unit load, KN/m	
initial	in.	Kips	in.	Kips	mm	KN	mm	KN	negative	positive	negative	positive
	0	0	0	0	0	0	0	0	0	0	0	0
1	-0.119	-1.462	0.076	1.593	-3.035	-6.504	1.930	7.085	0.087	0.061	-2.667	2.906
7	-0.165	-1.915	0.131	2.442	-4.181	-8.519	3.332	10.861	0.076	0.111	-3.494	4.454
14	-0.215	-2.488	0.181	3.221	-5.453	-11.066	4.587	14.326	0.110	0.140	-4.538	5.875
21	-0.411	-4.690	0.388	5.575	-10.439	-20.860	9.865	24.796	0.704	0.914	-8.555	10.169
25	-0.608	-6.616	0.586	7.870	-15.441	-29.429	14.887	35.008	1.113	1.329	-12.069	14.357
29	-0.800	-8.462	0.783	9.662	-20.315	-37.638	19.898	42.977	1.447	1.730	-15.435	17.625
32	-1.387	-12.652	1.384	13.729	-35.232	-56.278	35.164	61.067	6.200	7.029	-23.080	25.044
35	-1.645	-14.085	1.799	15.779	-41.793	-62.650	45.692	70.186	3.453	6.116	-25.693	28.784
38	-1.722	-7.934	2.542	14.419	-43.744	-35.292	64.567	64.137	0.846	11.220	-14.474	26.303

Specimen 4b	For total length		Specimen 4b	Per unit length	
	CUREE cyclic test			CUREE cyclic test	
Effective wall length	96in.	2.44m	Effective wall length	96in.	2.44m
Date:	Time:		Date:	Time:	
EEEP Parameters	units	initial	EEEP Parameters	units	initial
Peak load, F_{peak}	Kips	17.237	Peak unit load, v_{peak}	Kip/ft.	2.155
	KN	76.670		KN/m	31.443
Drift at peak load, Δ_{peak}	in.	2.962	Drift at capacity, Δ_{peak}	in.	2.962
	mm	75.23		mm	75.23
Yield load, F_{yield}	Kips	15.871	Yield unit load, v_{yield}	Kip/ft.	1.984
	KN	70.595		KN/m	28.951
Drift at yield load, Δ_{yield}	in.	1.150	Drift at yield load, Δ_{yield}	in.	1.150
	mm	29.21		mm	29.21
Proportional limit, $0.4F_{peak}$	Kips	6.895	Proportional limit, $0.4v_{peak}$	Kip/ft.	0.862
	KN	30.668		KN/m	12.577
Drift at prop. limit, $\Delta@0.4F_{peak}$	in.	0.499	Drift at prop. limit, $\Delta@0.4v_{peak}$	in.	0.499
	mm	12.69		mm	12.69
Failure load or $0.8F_{peak}$	Kips	14.311	Unit load at failure or $0.8v_{peak}$	Kip/ft.	1.789
	KN	63.653		KN/m	26.104
Drift at failure, $\Delta_{failure}$	in.	3.288	Drift at failure, $\Delta_{failure}$	in.	3.288
	mm	83.51		mm	83.51
Elastic stiffness, K_e @$0.4F_{peak}$	Kip/in.	13.805	Shear modulus, G @$0.4F_{peak}$	Kip/in.	13.805
	KN/mm	2.417		KN/mm	2.417
Work until failure	Kip·ft.	19.101	Work until failure per unit length	Kip·ft./ft.	2.388
	KN·m	25.896		KN·m/m	10.620
Load @ .32 in. (8.13 mm)	Kips	4.724	Unit load @ .32 in. (8.13 mm)	Kips/ft.	0.590
	KN	21.010		KN/m	8.616
Load @ .48 in. (12.19 mm)	Kips	6.664	Unit load @ .48 in. (12.19 mm)	Kips/ft.	0.833
	KN	29.642		KN/m	12.156
Load @ .96 in. (24.38 mm)	Kips	11.597	Unit load @ .96 in. (24.38 mm)	Kips/ft.	1.450
	KN	51.585		KN/m	21.155
Load @ 1.6 in. (40.64 mm)	Kips	15.815	Unit load @ 1.6 in. (40.64 mm)	Kips/ft.	1.977
	KN	70.347		KN/m	28.850
Ductility factor, μ		2.86	ζ_{eq} @v_{peak}		0.162

		initial	
EEEP Parameters	units	negative	positive
F_{yield}	Kips	-15.162	16.580
	KN	-67.440	73.750
v_{yield}	Kips/ft.	-1.895	2.073
	KN/m	-27.657	30.245
Δ_{yield}	in.	-1.154	1.146
	mm	-29.30	29.11
$\Delta_{failure}$	in.	-3.182	3.394
	mm	-80.81	86.22

Ultimate parameters		units	negative	positive	average
SLS	F_{SLS}	Kips	-16.415	18.059	17.237
		KN	-73.019	80.328	76.674

Specimen 4b		For total length												
		CUREE cyclic test												
Effective wall length		96in.	2.44m											
cycle	avg. displacement		avg. load		work per cycle		cumulative work		cyclic stiffness		damping ratio	line number
initial	in.	mm	Kips	KN	Kip·ft.	KN·m	Kip·ft.	KN·m	Kip/in.	KN/mm		
	0	0	0	0	0	0	0	0				13
1	0.103	2.614	1.917	8.527	0.009	0.013	0.009	0.013	18.794	3.291	0.092	102
7	0.153	3.896	2.648	11.780	0.020	0.027	0.075	0.102	17.328	3.034	0.093	704
14	0.208	5.279	3.346	14.884	0.033	0.044	0.175	0.237	16.120	2.823	0.090	1404
21	0.421	10.687	5.961	26.517	0.127	0.172	0.411	0.557	14.171	2.482	0.097	2103
25	0.628	15.950	8.418	37.445	0.255	0.346	0.855	1.160	13.406	2.348	0.092	2504
29	0.835	21.200	10.590	47.104	0.411	0.557	1.631	2.211	12.688	2.222	0.089	2904
32	1.451	36.853	15.543	69.136	1.386	1.879	3.400	4.609	10.714	1.876	0.117	3204
35	2.057	52.259	16.518	73.471	2.382	3.229	6.724	9.116	8.051	1.410	0.134	3504
38	2.962	75.235	17.237	76.670	4.342	5.887	12.563	17.032	5.819	1.019	0.162	3804
41	3.442	87.427	12.101	53.826	4.168	5.651	19.101	25.896	3.530	0.618	0.192	4104
44	3.315	84.204	4.722	21.002	0.682	0.924	20.668	28.021	1.420	0.249	0.083	4320
47	2.436	61.883	4.525	20.127	0.873	1.184	11.620	15.754	1.863	0.326	0.152	7545
50	3.228	81.980	3.282	14.597	0.818	1.109	15.975	21.658	1.019	0.178	0.148	8146

cycle	Negative stroke		Positive stroke		Negative stroke		Positive stroke		Area, Kip-in.		Unit load, KN/m	
initial	in.	Kips	in.	Kips	mm	KN	mm	KN	negative	positive	negative	positive
	0	0	0	0	0	0	0	0	0	0	0	0
1	-0.108	-1.656	0.098	2.178	-2.738	-7.368	2.489	9.686	0.089	0.107	-3.022	3.972
7	-0.157	-2.324	0.150	2.973	-3.993	-10.335	3.800	13.225	0.098	0.133	-4.239	5.424
14	-0.210	-3.004	0.206	3.689	-5.339	-13.360	5.220	16.409	0.141	0.186	-5.479	6.729
21	-0.422	-5.650	0.419	6.273	-10.719	-25.130	10.655	27.904	0.916	1.066	-10.306	11.443
25	-0.627	-8.072	0.629	8.765	-15.931	-35.905	15.969	38.985	1.408	1.573	-14.725	15.988
29	-0.836	-10.318	0.833	10.862	-21.237	-45.895	21.163	48.313	1.921	2.007	-18.822	19.813
32	-1.461	-15.348	1.440	15.739	-37.120	-68.266	36.586	70.006	8.024	8.076	-27.996	28.710
35	-2.123	-15.592	1.992	17.444	-53.919	-69.351	50.599	77.590	10.232	9.153	-28.441	31.820
38	-2.953	-16.415	2.971	18.059	-74.999	-73.015	75.471	80.324	13.281	17.382	-29.944	32.941
41	-3.490	-8.713	3.394	15.489	-88.638	-38.757	86.215	68.894	6.747	7.095	-15.894	28.254

Specimen 4d	For total length		Specimen 4d	Per unit length	
	CUREE cyclic test			CUREE cyclic test	
Effective wall length	96in.	2.44m	Effective wall length	96in.	2.44m
Date:	Time:		Date:	Time:	
EEEP Parameters	units	initial	EEEP Parameters	units	initial
Peak load, F_{peak}	Kips	15.328	Peak unit load, v_{peak}	Kip/ft.	1.916
	KN	68.178		KN/m	27.960
Drift at peak load, Δ_{peak}	in.	2.891	Drift at capacity, Δ_{peak}	in.	2.891
	mm	73.43		mm	73.43
Yield load, F_{yield}	Kips	13.782	Yield unit load, v_{yield}	Kip/ft.	1.723
	KN	61.304		KN/m	25.141
Drift at yield load, Δ_{yield}	in.	1.120	Drift at yield load, Δ_{yield}	in.	1.120
	mm	28.46		mm	28.46
Proportional limit, $0.4F_{peak}$	Kips	6.131	Proportional limit, $0.4v_{peak}$	Kip/ft.	0.766
	KN	27.271		KN/m	11.184
Drift at prop. limit, $\Delta@0.4F_{peak}$	in.	0.498	Drift at prop. limit, $\Delta@0.4v_{peak}$	in.	0.498
	mm	12.66		mm	12.66
Failure load or $0.8F_{peak}$	Kips	13.667	Unit load at failure or $0.8v_{peak}$	Kip/ft.	1.708
	KN	60.790		KN/m	24.930
Drift at failure, $\Delta_{failure}$	in.	3.560	Drift at failure, $\Delta_{failure}$	in.	3.560
	mm	90.44		mm	90.44
Elastic stiffness, K_e @$0.4F_{peak}$	Kip/in.	12.359	Shear modulus, G @$0.4F_{peak}$	Kip/in.	12.359
	KN/mm	2.164		KN/mm	2.164
Work until failure	Kip·ft.	19.172	Work until failure per unit length	Kip·ft./ft.	2.396
	KN·m	25.992		KN·m/m	10.660
Load @ .32 in. (8.13 mm)	Kips	4.479	Unit load @ .32 in. (8.13 mm)	Kips/ft.	0.560
	KN	19.924		KN/m	8.171
Load @ .48 in. (12.19 mm)	Kips	5.964	Unit load @ .48 in. (12.19 mm)	Kips/ft.	0.745
	KN	26.526		KN/m	10.879
Load @ .96 in. (24.38 mm)	Kips	9.602	Unit load @ .96 in. (24.38 mm)	Kips/ft.	1.200
	KN	42.708		KN/m	17.515
Load @ 1.6 in. (40.64 mm)	Kips	13.019	Unit load @ 1.6 in. (40.64 mm)	Kips/ft.	1.627
	KN	57.910		KN/m	23.749
Ductility factor, μ		3.22	ζ_{eq} @v_{peak}		0.178

		initial	
EEEP Parameters	units	negative	positive
F_{yield}	Kips	-14.199	13.366
	KN	-63.155	59.453
v_{yield}	Kips/ft.	-1.775	1.671
	KN/m	-25.900	24.382
Δ_{yield}	in.	-1.216	1.025
	mm	-30.88	26.04
$\Delta_{failure}$	in.	-3.336	3.785
	mm	-84.74	96.13

Ultimate parameters		units	negative	positive	average
SLS	F_{SLS}	Kips	-15.822	14.834	15.328
		KN	-70.379	65.984	68.182

Specimen 4d	For total length	
	CUREE cyclic test	
Effective wall length	96in.	2.44m

cycle	avg. displacement		avg. load		work per cycle		cumulative work		cyclic stiffness		damping ratio	line number
initial	in.	mm	Kips	KN	Kip·ft.	KN·m	Kip·ft.	KN·m	Kip/in.	KN/mm		
	0	0	0	0	0	0	0	0				13
1	0.064	1.624	1.506	6.701	0.006	0.008	0.006	0.008	23.547	4.123	0.118	66
7	0.153	3.880	2.834	12.607	0.022	0.030	0.079	0.108	18.550	3.249	0.099	467
14	0.207	5.257	3.395	15.100	0.040	0.055	0.195	0.265	16.418	2.875	0.110	935
21	0.420	10.663	5.434	24.171	0.145	0.197	0.468	0.634	12.951	2.268	0.122	1401
25	0.637	16.173	7.344	32.665	0.267	0.361	0.959	1.300	11.532	2.019	0.109	1667
29	0.852	21.648	8.980	39.944	0.413	0.560	1.765	2.393	10.536	1.845	0.103	1934
32	1.492	37.899	12.643	56.236	1.293	1.753	3.445	4.670	8.475	1.484	0.131	2134
35	2.104	53.444	14.758	65.642	2.158	2.926	6.471	8.774	7.014	1.228	0.133	2334
38	2.891	73.431	15.328	68.178	4.128	5.597	12.017	16.292	5.341	0.935	0.178	2534
41	3.560	90.435	13.667	60.790	4.918	6.668	19.172	25.992	3.862	0.676	0.193	2734
44	3.315	84.204	4.722	21.002	0.682	0.924	20.668	28.021	1.420	0.249	0.083	4320
47	2.436	61.883	4.525	20.127	0.873	1.184	11.620	15.754	1.863	0.326	0.152	7545
50	3.228	81.980	3.282	14.597	0.818	1.109	15.975	21.658	1.019	0.178	0.148	8146

cycle	Negative stroke		Positive stroke		Negative stroke		Positive stroke		Area, Kip-in.		Unit load, KN/m	
initial	in.	Kips	in.	Kips	mm	KN	mm	KN	negative	positive	negative	positive
	0	0	0	0	0	0	0	0	0	0	0	0
1	-0.068	-1.616	0.060	1.397	-1.732	-7.188	1.516	6.213	0.055	0.042	-2.948	2.548
7	-0.150	-2.747	0.155	2.922	-3.818	-12.218	3.942	12.995	0.179	0.206	-5.011	5.329
14	-0.211	-3.297	0.203	3.493	-5.349	-14.666	5.164	15.535	0.182	0.154	-6.014	6.371
21	-0.425	-5.286	0.415	5.583	-10.792	-23.510	10.533	24.831	0.920	0.959	-9.642	10.183
25	-0.634	-7.147	0.640	7.541	-16.096	-31.789	16.251	33.541	1.298	1.477	-13.037	13.755
29	-0.845	-8.841	0.859	9.120	-21.468	-39.323	21.829	40.564	1.691	1.829	-16.127	16.636
32	-1.480	-12.857	1.505	12.429	-37.582	-57.187	38.217	55.285	6.882	6.952	-23.453	22.673
35	-2.104	-15.222	2.104	14.294	-53.452	-67.706	53.437	63.578	8.772	8.006	-27.766	26.074
38	-2.687	-15.822	3.095	14.834	-68.242	-70.376	78.621	65.981	9.038	14.440	-28.861	27.059
41	-3.336	-14.112	3.785	13.222	-84.737	-62.768	96.134	58.811	9.719	9.672	-25.741	24.119

Specimen 5b	For total length		Specimen 5b	Per unit length	
	CUREE cyclic test			CUREE cyclic test	
Effective wall length	96in.	2.44m	Effective wall length	96in.	2.44m
Date:	Time:		Date:	Time:	
EEEP Parameters	units	initial	EEEP Parameters	units	initial
Peak load, F_{peak}	Kips	13.486	Peak unit load, v_{peak}	Kip/ft.	1.686
	KN	59.988		KN/m	24.601
Drift at peak load, Δ_{peak}	in.	3.625	Drift at capacity, Δ_{peak}	in.	3.625
	mm	92.09		mm	92.09
Yield load, F_{yield}	Kips	11.789	Yield unit load, v_{yield}	Kip/ft.	1.474
	KN	52.436		KN/m	21.504
Drift at yield load, Δ_{yield}	in.	1.615	Drift at yield load, Δ_{yield}	in.	1.615
	mm	41.03		mm	41.03
Proportional limit, $0.4F_{peak}$	Kips	5.395	Proportional limit, $0.4v_{peak}$	Kip/ft.	0.674
	KN	23.995		KN/m	9.840
Drift at prop. limit, $\Delta@0.4F_{peak}$	in.	0.739	Drift at prop. limit, $\Delta@0.4v_{peak}$	in.	0.739
	mm	18.77		mm	18.77
Failure load or $0.8F_{peak}$	Kips	13.296	Unit load at failure or $0.8v_{peak}$	Kip/ft.	1.662
	KN	59.139		KN/m	24.253
Drift at failure, $\Delta_{failure}$	in.	3.794	Drift at failure, $\Delta_{failure}$	in.	3.794
	mm	96.36		mm	96.36
Elastic stiffness, K_e $@0.4F_{peak}$	Kip/in.	7.331	Shear modulus, G $@0.4F_{peak}$	Kip/in	7.331
	KN/mm	1.284		KN/mm	1.284
Work until failure	Kip·ft.	13.266	Work until failure per unit length	Kip·ft./ft.	1.658
	KN·m	17.985		KN·m/m	7.376
Load @ .32 in. (8.13 mm)	Kips	2.826	Unit load @ .32 in. (8.13 mm)	Kips/ft.	0.353
	KN	12.572		KN/m	5.156
Load @ .48 in. (12.19 mm)	Kips	3.857	Unit load @ .48 in. (12.19 mm)	Kips/ft.	0.482
	KN	17.157		KN/m	7.036
Load @ .96 in. (24.38 mm)	Kips	6.562	Unit load @ .96 in. (24.38 mm)	Kips/ft.	0.820
	KN	29.187		KN/m	11.970
Load @ 1.6 in. (40.64 mm)	Kips	9.478	Unit load @ 1.6 in. (40.64 mm)	Kips/ft.	1.185
	KN	42.157		KN/m	17.289
Ductility factor, μ		2.35	$\zeta_{eq}@v_{peak}$		0.139

		initial	
EEEP Parameters	units	negative	positive
F_{yield}	Kips	-11.685	11.892
	KN	-51.974	52.897
v_{yield}	Kips/ft	-1.461	1.487
	KN/m	-21.315	21.693
Δ_{yield}	in.	-1.499	1.732
	mm	-38.08	43.98
$\Delta_{failure}$	in.	-3.453	4.134
	mm	-87.71	105.00

Ultimate parameters		units	negative	positive	average
SLS	F_{SLS}	Kips	-13.404	13.568	13.486
		KN	-59.625	60.356	59.991

Specimen 5b		For total length	
		CUREE cyclic test	
Effective wall length		96in.	2.44m

cycle	avg. displacement		avg. load		work per cycle		cumulative work		cyclic stiffness		damping ratio	line number
initial	in.	mm	Kips	KN	Kip·ft.	KN·m	Kip·ft.	KN·m	Kip/in.	KN/mm		
	0	0	0	0	0	0	0	0				13
1	0.101	2.577	1.250	5.559	0.008	0.011	0.008	0.011	12.317	2.157	0.119	102
7	0.156	3.970	1.696	7.543	0.015	0.020	0.057	0.077	10.825	1.896	0.105	704
14	0.209	5.302	2.095	9.316	0.023	0.031	0.128	0.173	10.015	1.754	0.100	1403
21	0.424	10.766	3.512	15.622	0.081	0.110	0.286	0.388	8.282	1.450	0.104	2103
25	0.636	16.166	4.821	21.446	0.151	0.205	0.555	0.753	7.580	1.327	0.094	2502
29	0.853	21.667	6.046	26.891	0.240	0.325	1.019	1.382	7.089	1.241	0.089	2902
32	1.499	38.086	9.156	40.725	0.785	1.064	2.035	2.759	6.108	1.070	0.109	3202
35	2.134	54.193	11.198	49.811	1.402	1.901	3.995	5.416	5.249	0.919	0.112	3502
38	3.107	78.910	13.167	58.567	2.892	3.920	7.841	10.631	4.238	0.742	0.135	3803
41	3.794	96.356	13.296	59.139	3.790	5.139	13.266	17.985	3.527	0.618	0.143	4103
44	3.315	84.204	4.722	21.002	0.682	0.924	20.668	28.021	1.420	0.249	0.083	4320
47	2.436	61.883	4.525	20.127	0.873	1.184	11.620	15.754	1.863	0.326	0.152	7545
50	3.228	81.980	3.282	14.597	0.818	1.109	15.975	21.658	1.019	0.178	0.148	8146

cycle	Negative stroke		Positive stroke		Negative stroke		Positive stroke		Area, Kip-in.		Unit load, KN/m	
initial	in.	Kips	in.	Kips	mm	KN	mm	KN	negative	positive	negative	positive
	0	0	0	0	0	0	0	0	0	0	0	0
1	-0.112	-1.382	0.091	1.117	-2.847	-6.147	2.306	4.970	0.077	0.051	-2.521	2.038
7	-0.166	-1.862	0.147	1.529	-4.204	-8.283	3.736	6.803	0.087	0.075	-3.397	2.790
14	-0.219	-2.277	0.199	1.912	-5.550	-10.128	5.055	8.505	0.110	0.089	-4.153	3.488
21	-0.429	-3.699	0.419	3.325	-10.886	-16.454	10.645	14.789	0.628	0.576	-6.748	6.065
25	-0.630	-5.024	0.643	4.619	-15.997	-22.345	16.335	20.546	0.878	0.890	-9.164	8.426
29	-0.849	-6.296	0.857	5.795	-21.562	-28.005	21.773	25.777	1.240	1.115	-11.485	10.571
32	-1.490	-9.586	1.509	8.725	-37.841	-42.640	38.331	38.809	5.090	4.733	-17.487	15.916
35	-2.134	-11.507	2.134	10.890	-54.196	-51.185	54.191	48.437	6.791	6.124	-20.991	19.864
38	-3.117	-13.404	3.096	12.930	-79.169	-59.622	78.651	57.512	12.247	11.469	-24.451	23.586
41	-3.453	-13.023	4.134	13.568	-87.709	-57.926	105.004	60.353	4.442	13.746	-23.756	24.751

Specimen 5d	For total length		Specimen 5d	Per unit length	
	CUREE cyclic test			CUREE cyclic test	
Effective wall length	96in.	2.44m	Effective wall length	96in.	2.44m
Date:	Time:		Date:	Time:	
EEEP Parameters	units	initial	EEEP Parameters	units	initial
Peak load, F_{peak}	Kips	11.682	Peak unit load, v_{peak}	Kip/ft.	1.460
	KN	51.959		KN/m	21.309
Drift at peak load, Δ_{peak}	in.	3.495	Drift at capacity, Δ_{peak}	in.	3.495
	mm	88.76		mm	88.76
Yield load, F_{yield}	Kips	10.295	Yield unit load, v_{yield}	Kip/ft.	1.287
	KN	45.793		KN/m	18.780
Drift at yield load, Δ_{yield}	in.	1.237	Drift at yield load, Δ_{yield}	in.	1.237
	mm	31.41		mm	31.41
Proportional limit, $0.4F_{peak}$	Kips	4.673	Proportional limit, $0.4v_{peak}$	Kip/ft.	0.584
	KN	20.784		KN/m	8.524
Drift at prop. limit, $\Delta@0.4F_{peak}$	in.	0.561	Drift at prop. limit, $\Delta@0.4v_{peak}$	in.	0.561
	mm	14.26		mm	14.26
Failure load or $0.8F_{peak}$	Kips	11.682	Unit load at failure or $0.8v_{peak}$	Kip/ft.	1.460
	KN	51.959		KN/m	21.309
Drift at failure, $\Delta_{failure}$	in.	3.495	Drift at failure, $\Delta_{failure}$	in.	3.495
	mm	88.76		mm	88.76
Elastic stiffness, K_e @$0.4F_{peak}$	Kip/in.	8.313	Shear modulus, G @$0.4F_{peak}$	Kip/in.	8.313
	KN/mm	1.456		KN/mm	1.456
Work until failure	Kip·ft.	10.572	Work until failure per unit length	Kip·ft./ft.	1.322
	KN·m	14.334		KN·m/m	5.878
Load @ .32 in. (8.13 mm)	Kips	3.072	Unit load @ .32 in. (8.13 mm)	Kips/ft.	0.384
	KN	13.663		KN/m	5.603
Load @ .48 in. (12.19 mm)	Kips	4.146	Unit load @ .48 in. (12.19 mm)	Kips/ft.	0.518
	KN	18.444		KN/m	7.564
Load @ .96 in. (24.38 mm)	Kips	6.693	Unit load @ .96 in. (24.38 mm)	Kips/ft.	0.837
	KN	29.769		KN/m	12.209
Load @ 1.6 in. (40.64 mm)	Kips	9.176	Unit load @ 1.6 in. (40.64 mm)	Kips/ft.	1.147
	KN	40.813		KN/m	16.738
Ductility factor, μ		2.82	ζ_{eq} @v_{peak}		0.127

		initial	
EEEP Parameters	units	negative	positive
F_{yield}	Kips	-9.479	11.111
	KN	-42.163	49.423
v_{yield}	Kips/ft.	-1.185	1.389
	KN/m	-17.291	20.269
Δ_{yield}	in.	-1.171	1.302
	mm	-29.74	33.08
$\Delta_{failure}$	in.	-3.262	3.727
	mm	-82.86	94.66

Ultimate parameters		units	negative	positive	average
SLS	F_{SLS}	Kips	-10.832	12.531	11.682
		KN	-48.184	55.740	51.962

Specimen 5d		For total length											
		CUREE cyclic test											
Effective wall length		96in.	2.44m										
cycle	avg. displacement		avg. load		work per cycle		cumulative work		cyclic stiffness		damping ratio	line number
initial	in.	mm	Kips	KN	Kip·ft.	KN·m	Kip·ft.	KN·m	Kip/in.	KN/mm		
	0	0	0	0	0	0	0	0				13
1	0.043	1.104	0.721	3.207	0.002	0.003	0.002	0.003	16.634	2.913	0.137	200
7	0.142	3.599	1.698	7.552	0.013	0.018	0.037	0.050	11.984	2.099	0.104	1403
14	0.190	4.821	2.117	9.414	0.020	0.027	0.100	0.136	11.152	1.953	0.095	2802
21	0.382	9.707	3.534	15.721	0.068	0.093	0.236	0.319	9.243	1.619	0.097	4202
25	0.575	14.600	4.760	21.173	0.133	0.180	0.473	0.641	8.270	1.448	0.092	5003
29	0.761	19.340	5.825	25.909	0.209	0.284	0.877	1.189	7.636	1.337	0.090	5803
32	1.335	33.914	8.358	37.175	0.658	0.893	1.742	2.362	6.248	1.094	0.112	6403
35	1.886	47.912	10.058	44.737	1.129	1.531	3.372	4.572	5.324	0.932	0.113	7004
38	2.777	70.542	11.497	51.140	2.240	3.036	6.437	8.726	4.135	0.724	0.134	7605
41	3.495	88.762	11.682	51.959	2.724	3.693	10.572	14.334	3.341	0.585	0.127	8209
44	0.332	8.430	0.401	1.784	0.019	0.026	19.974	27.079	1.026	0.180	0.217	8806
47	2.436	61.883	4.525	20.127	0.873	1.184	11.620	15.754	1.863	0.326	0.152	7545
50	3.228	81.980	3.282	14.597	0.818	1.109	15.975	21.658	1.019	0.178	0.148	8146

cycle	Negative stroke		Positive stroke		Negative stroke		Positive stroke		Area, Kip-in.		Unit load, KN/m	
initial	in.	Kips	in.	Kips	mm	KN	mm	KN	negative	positive	negative	positive
	0	0	0	0	0	0	0	0	0	0	0	0
1	-0.042	-0.771	0.045	0.671	-1.074	-3.430	1.133	2.983	0.016	0.015	-1.407	1.223
7	-0.138	-1.674	0.145	1.722	-3.515	-7.445	3.683	7.659	0.117	0.120	-3.053	3.141
14	-0.182	-2.026	0.198	2.207	-4.610	-9.013	5.032	9.815	0.080	0.104	-3.696	4.025
21	-0.362	-3.306	0.402	3.763	-9.202	-14.703	10.211	16.739	0.482	0.609	-6.030	6.865
25	-0.542	-4.371	0.608	5.149	-13.759	-19.442	15.441	22.904	0.689	0.918	-7.973	9.393
29	-0.719	-5.312	0.804	6.338	-18.263	-23.628	20.417	28.190	0.858	1.125	-9.690	11.561
32	-1.259	-7.606	1.411	9.110	-31.989	-33.830	35.839	40.520	3.490	4.690	-13.874	16.617
35	-1.803	-9.288	1.970	10.827	-45.786	-41.314	50.038	48.160	4.588	5.572	-16.943	19.751
38	-2.662	-10.700	2.893	12.295	-67.605	-47.593	73.480	54.687	8.585	10.670	-19.518	22.428
41	-3.262	-10.832	3.727	12.531	-82.862	-48.181	94.661	55.737	6.467	10.351	-19.759	22.858

Specimen 6a	For total length		Specimen 6a	Per unit length	
	CUREE cyclic test			CUREE cyclic test	
Effective wall length	96in.	2.44m	Effective wall length	96in.	2.44m
Date:	Time:		Date:	Time:	
EEEP Parameters	units	initial	EEEP Parameters	units	initial
Peak load, F_{peak}	Kips	11.780	Peak unit load, v_{peak}	Kip/ft.	1.472
	KN	52.396		KN/m	21.488
Drift at peak load, Δ_{peak}	in.	2.372	Drift at capacity, Δ_{peak}	in.	2.372
	mm	60.26		mm	60.26
Yield load, F_{yield}	Kips	10.678	Yield unit load, v_{yield}	Kip/ft.	1.335
	KN	47.496		KN/m	19.478
Drift at yield load, Δ_{yield}	in.	0.533	Drift at yield load, Δ_{yield}	in.	0.533
	mm	13.53		mm	13.53
Proportional limit, $0.4F_{peak}$	Kips	4.712	Proportional limit, $0.4v_{peak}$	Kip/ft.	0.589
	KN	20.958		KN/m	8.595
Drift at prop. limit, $\Delta@0.4F_{peak}$	in.	0.235	Drift at prop. limit, $\Delta@0.4v_{peak}$	in.	0.235
	mm	5.96		mm	5.96
Failure load or $0.8F_{peak}$	Kips	11.246	Unit load at failure or $0.8v_{peak}$	Kip/ft.	1.406
	KN	50.024		KN/m	20.515
Drift at failure, $\Delta_{failure}$	in.	3.639	Drift at failure, $\Delta_{failure}$	in.	3.639
	mm	92.43		mm	92.43
Elastic stiffness, K_e @$0.4F_{peak}$	Kip/in.	20.019	Shear modulus, G @$0.4F_{peak}$	Kip/in.	20.019
	KN/mm	3.506		KN/mm	3.506
Work until failure	Kip·ft.	13.279	Work until failure per unit length	Kip·ft./ft.	1.660
	KN·m	18.002		KN·m/m	7.383
Load @ .32 in. (8.13 mm)	Kips	5.922	Unit load @ .32 in. (8.13 mm)	Kips/ft.	0.740
	KN	26.343		KN/m	10.803
Load @ .48 in. (12.19 mm)	Kips	7.615	Unit load @ .48 in. (12.19 mm)	Kips/ft.	0.952
	KN	33.870		KN/m	13.890
Load @ .96 in. (24.38 mm)	Kips	9.636	Unit load @ .96 in. (24.38 mm)	Kips/ft.	1.205
	KN	42.861		KN/m	17.578
Load @ 1.6 in. (40.64 mm)	Kips	10.583	Unit load @ 1.6 in. (40.64 mm)	Kips/ft.	1.323
	KN	47.073		KN/m	19.305
Ductility factor, μ		6.83	ζ_{eq} @v_{peak}		0.153

		initial	
EEEP Parameters	units	negative	positive
F_{yield}	Kips	-9.618	11.738
	KN	-42.781	52.211
v_{yield}	Kips/ft.	-1.202	1.467
	KN/m	-17.545	21.412
Δ_{yield}	in.	-0.527	0.539
	mm	-13.38	13.69
$\Delta_{failure}$	in.	-3.738	3.540
	mm	-94.94	89.93

Ultimate parameters		units	negative	positive	average
SLS	F_{SLS}	Kips	-10.596	13.301	11.948
		KN	-47.132	59.165	53.149

Specimen 6a	For total length	
	CUREE cyclic test	
Effective wall length	96in.	2.44m

cycle	avg. displacement		avg. load		work per cycle		cumulative work		cyclic stiffness		damping	line
initial	in.	mm	Kips	KN	Kip·ft.	KN·m	Kip·ft.	KN·m	Kip/in.	KN/mm	ratio	number
	0	0	0	0	0	0	0	0				13
1	0.026	0.652	0.839	3.733	0.002	0.002	0.002	0.002	38.270	6.702	0.169	122
7	0.113	2.861	2.780	12.367	0.015	0.020	0.043	0.058	24.543	4.298	0.091	870
14	0.152	3.870	3.513	15.627	0.025	0.034	0.120	0.163	22.927	4.015	0.088	1744
21	0.321	8.147	5.974	26.572	0.096	0.130	0.301	0.407	18.547	3.248	0.095	2618
25	0.503	12.769	7.862	34.968	0.202	0.274	0.644	0.873	15.588	2.730	0.097	3118
29	0.688	17.480	9.201	40.926	0.336	0.456	1.257	1.704	13.335	2.335	0.101	3618
32	1.065	27.050	10.296	45.798	1.151	1.560	2.705	3.667	9.976	1.747	0.203	3993
35	1.905	48.377	11.286	50.202	1.532	2.077	4.883	6.620	5.914	1.036	0.136	4368
38	2.496	63.401	11.948	53.146	2.711	3.676	8.591	11.647	4.833	0.846	0.170	4743
41	3.639	92.434	11.246	50.024	3.181	4.313	13.279	18.002	3.103	0.543	0.149	5118
44	0.332	8.430	0.401	1.784	0.019	0.026	19.974	27.079	1.026	0.180	0.217	8806
47	2.436	61.883	4.525	20.127	0.873	1.184	11.620	15.754	1.863	0.326	0.152	7545
50	3.228	81.980	3.282	14.597	0.818	1.109	15.975	21.658	1.019	0.178	0.148	8146

cycle	Negative stroke		Positive stroke		Negative stroke		Positive stroke		Area, Kip-in.		Unit load, KN/m	
initial	in.	Kips	in.	Kips	mm	KN	mm	KN	negative	positive	negative	positive
	0	0	0	0	0	0	0	0	0	0	0	0
1	-0.034	-0.757	0.017	0.922	-0.874	-3.368	0.429	4.099	0.013	0.008	-1.381	1.681
7	-0.108	-2.292	0.117	3.269	-2.741	-10.196	2.982	14.538	0.112	0.211	-4.181	5.963
14	-0.144	-2.961	0.161	4.066	-3.645	-13.169	4.094	18.086	0.094	0.161	-5.401	7.417
21	-0.302	-5.197	0.339	6.751	-7.681	-23.115	8.613	30.029	0.648	0.962	-9.480	12.315
25	-0.470	-6.960	0.535	8.763	-11.938	-30.958	13.599	38.979	1.019	1.523	-12.696	15.985
29	-0.637	-8.190	0.740	10.211	-16.167	-36.431	18.793	45.420	1.261	1.940	-14.941	18.627
32	-1.216	-9.502	1.412	10.635	-30.894	-42.263	35.865	47.304	5.129	7.005	-17.332	19.400
35	-1.827	-10.258	1.982	12.314	-46.416	-45.629	50.338	54.774	6.038	6.538	-18.713	22.463
38	-2.909	-9.894	2.917	13.301	-73.894	-44.008	74.097	59.162	10.900	11.980	-18.048	24.263
41	-3.738	-9.907	3.540	12.586	-94.940	-44.068	89.929	55.980	8.204	8.067	-18.073	22.958

Specimen 6b	For total length		Specimen 6b	Per unit length	
	CUREE cyclic test			CUREE cyclic test	
Effective wall length	96in.	2.44m	Effective wall length	96in.	2.44m
Date:	Time:		Date:	Time:	
EEEP Parameters	units	initial	EEEP Parameters	units	initial
Peak load, F_{peak}	Kips	13.582	Peak unit load, v_{peak}	Kip/ft.	1.698
	KN	60.412		KN/m	24.775
Drift at peak load, Δ_{peak}	in.	2.971	Drift at capacity, Δ_{peak}	in.	2.971
	mm	75.47		mm	75.47
Yield load, F_{yield}	Kips	12.334	Yield unit load, v_{yield}	Kip/ft.	1.542
	KN	54.860		KN/m	22.499
Drift at yield load, Δ_{yield}	in.	0.516	Drift at yield load, Δ_{yield}	in.	0.516
	mm	13.11		mm	13.11
Proportional limit, $0.4F_{peak}$	Kips	5.433	Proportional limit, $0.4v_{peak}$	Kip/ft.	0.679
	KN	24.165		KN/m	9.910
Drift at prop. limit, $\Delta@0.4F_{peak}$	in.	0.227	Drift at prop. limit, $\Delta@0.4v_{peak}$	in.	0.227
	mm	5.77		mm	5.77
Failure load or $0.8F_{peak}$	Kips	10.866	Unit load at failure or $0.8v_{peak}$	Kip/ft.	1.358
	KN	48.330		KN/m	19.820
Drift at failure, $\Delta_{failure}$	in.	3.261	Drift at failure, $\Delta_{failure}$	in.	3.261
	mm	82.82		mm	82.82
Elastic stiffness, K_e @$0.4F_{peak}$	Kip/in.	23.900	Shear modulus, G @$0.4F_{peak}$	Kip/in.	23.900
	KN/mm	4.185		KN/mm	4.185
Work until failure	Kip·ft.	19.974	Work until failure per unit length	Kip·ft./ft.	2.497
	KN·m	27.079		KN·m/m	11.105
Load @ .32 in. (8.13 mm)	Kips	6.975	Unit load @ .32 in. (8.13 mm)	Kips/ft.	0.872
	KN	31.023		KN/m	12.723
Load @ .48 in. (12.19 mm)	Kips	9.086	Unit load @ .48 in. (12.19 mm)	Kips/ft.	1.136
	KN	40.414		KN/m	16.574
Load @ .96 in. (24.38 mm)	Kips	11.132	Unit load @ .96 in. (24.38 mm)	Kips/ft.	1.392
	KN	49.516		KN/m	20.307
Load @ 1.6 in. (40.64 mm)	Kips	12.256	Unit load @ 1.6 in. (40.64 mm)	Kips/ft.	1.532
	KN	54.517		KN/m	22.358
Ductility factor, μ		6.35	ζ_{eq} @v_{peak}		0.166

		initial	
EEEP Parameters	units	negative	positive
F_{yield}	Kips	-11.523	13.144
	KN	-51.256	58.465
v_{yield}	Kips/ft.	-1.440	1.643
	KN/m	-21.020	23.977
Δ_{yield}	in.	-0.480	0.552
	mm	-12.20	14.03
$\Delta_{failure}$	in.	-3.243	3.974
	mm	-82.37	101.35

Ultimate parameters		units	negative	positive	average
SLS	F_{SLS}	Kips	-13.026	14.138	13.582
		KN	-57.943	62.888	60.415

Specimen 6b		For total length	
		CUREE cyclic test	
Effective wall length		96in.	2.44m

cycle	avg. displacement		avg. load		work per cycle		cumulative work		cyclic stiffness		damping ratio	line number
initial	in.	mm	Kips	KN	Kip·ft.	KN·m	Kip·ft.	KN·m	Kip/in.	KN/mm		
	0	0	0	0	0	0	0	0				13
1	0.090	2.287	2.752	12.241	0.012	0.017	0.012	0.017	30.560	5.352	0.094	196
7	0.139	3.537	3.777	16.800	0.024	0.033	0.092	0.125	27.134	4.752	0.088	1399
14	0.185	4.693	4.719	20.992	0.039	0.052	0.216	0.293	25.547	4.474	0.085	2799
21	0.364	9.251	7.723	34.351	0.134	0.182	0.492	0.667	21.207	3.714	0.091	4198
25	0.544	13.825	9.830	43.723	0.292	0.396	1.013	1.373	18.067	3.164	0.104	4998
29	0.754	19.158	10.799	48.033	0.477	0.647	1.918	2.601	14.371	2.517	0.111	5798
32	1.257	31.935	11.677	51.938	1.451	1.967	3.811	5.166	9.287	1.626	0.189	6398
35	1.992	50.601	12.838	57.103	1.890	2.562	6.623	8.979	6.454	1.130	0.141	6998
38	2.971	75.474	13.582	60.412	3.520	4.773	11.486	15.572	4.586	0.803	0.166	7599
41	3.614	91.788	12.186	54.205	4.515	6.121	18.138	24.591	3.358	0.588	0.193	8199
44	0.332	8.430	0.401	1.784	0.019	0.026	19.974	27.079	1.026	0.180	0.217	8806
47	2.436	61.883	4.525	20.127	0.873	1.184	11.620	15.754	1.863	0.326	0.152	7545
50	3.228	81.980	3.282	14.597	0.818	1.109	15.975	21.658	1.019	0.178	0.148	8146

cycle	Negative stroke		Positive stroke		Negative stroke		Positive stroke		Area, Kip-in.		Unit load, KN/m	
initial	in.	Kips	in.	Kips	mm	KN	mm	KN	negative	positive	negative	positive
	0	0	0	0	0	0	0	0	0	0	0	0
1	-0.092	-2.829	0.088	2.675	-2.347	-12.585	2.228	11.897	0.131	0.117	-5.161	4.879
7	-0.136	-3.766	0.142	3.788	-3.459	-16.750	3.614	16.849	0.144	0.176	-6.869	6.910
14	-0.180	-4.605	0.190	4.834	-4.569	-20.481	4.816	21.503	0.183	0.204	-8.400	8.819
21	-0.338	-7.187	0.390	8.259	-8.598	-31.967	9.903	36.735	0.935	1.311	-13.110	15.065
25	-0.506	-9.187	0.583	10.473	-12.845	-40.864	14.806	46.582	1.369	1.808	-16.758	19.104
29	-0.683	-10.201	0.826	11.396	-17.348	-45.376	20.968	50.690	1.719	2.653	-18.609	20.788
32	-1.256	-10.905	1.258	12.449	-31.913	-48.504	31.958	55.372	6.051	5.159	-19.892	22.708
35	-1.867	-12.334	2.117	13.342	-47.424	-54.861	53.777	59.345	7.096	11.077	-22.499	24.338
38	-2.728	-13.026	3.214	14.138	-69.299	-57.940	81.648	62.885	10.920	15.077	-23.761	25.789
41	-3.253	-10.455	3.974	13.918	-82.624	-46.504	100.952	61.906	6.159	10.661	-19.071	25.388
44	-0.219	-0.107	0.444	0.695	-5.573	-0.475	11.288	3.093	-16.020	-25.793	-0.195	1.269

Specimen 7a	For total length	
	CUREE cyclic test	
Effective wall length	96in.	2.44m
Date:	Time:	
EEEP Parameters	units	initial
Peak load, F_{peak}	Kips	12.536
	KN	55.762
Drift at peak load, Δ_{peak}	in.	2.245
	mm	57.02
Yield load, F_{yield}	Kips	11.046
	KN	49.132
Drift at yield load, Δ_{yield}	in.	0.648
	mm	16.46
Proportional limit, $0.4F_{peak}$	Kips	5.015
	KN	22.305
Drift at prop. limit, $\Delta@0.4F_{peak}$	in.	0.294
	mm	7.47
Failure load or $0.8F_{peak}$	Kips	10.029
	KN	44.610
Drift at failure, $\Delta_{failure}$	in.	2.994
	mm	76.05
Elastic stiffness, K_e @$0.4F_{peak}$	Kip/in.	17.057
	KN/mm	2.987
Work until failure	Kip·ft.	16.342
	KN·m	22.155
Load @ .32 in. (8.13 mm)	Kips	5.316
	KN	23.648
Load @ .48 in. (12.19 mm)	Kips	6.971
	KN	31.007
Load @ .96 in. (24.38 mm)	Kips	9.844
	KN	43.787
Load @ 1.6 in. (40.64 mm)	Kips	11.688
	KN	51.989
Ductility factor, μ		4.62

Specimen 7a	Per unit length	
	CUREE cyclic test	
Effective wall length	96in.	2.44m
Date:	Time:	
EEEP Parameters	units	initial
Peak unit load, v_{peak}	Kip/ft.	1.567
	KN/m	22.868
Drift at capacity, Δ_{peak}	in.	2.245
	mm	57.02
Yield unit load, v_{yield}	Kip/ft.	1.381
	KN/m	20.149
Drift at yield load, Δ_{yield}	in.	0.648
	mm	16.46
Proportional limit, $0.4v_{peak}$	Kip/ft.	0.627
	KN/m	9.147
Drift at prop. limit, $\Delta@0.4v_{peak}$	in.	0.294
	mm	7.47
Unit load at failure or $0.8v_{peak}$	Kip/ft.	1.254
	KN/m	18.295
Drift at failure, $\Delta_{failure}$	in.	2.994
	mm	76.05
Shear modulus, G @$0.4F_{peak}$	Kip/in	17.057
	KN/mm	2.987
Work until failure per unit length	Kip·ft./ft.	2.043
	KN·m/m	9.086
Unit load @ .32 in. (8.13 mm)	Kips/ft	0.665
	KN/m	9.698
Unit load @ .48 in. (12.19 mm)	Kips/ft	0.871
	KN/m	12.716
Unit load @ .96 in. (24.38 mm)	Kips/ft	1.231
	KN/m	17.957
Unit load @ 1.6 in. (40.64 mm)	Kips/ft	1.461
	KN/m	21.321
ζ_{eq} @v_{peak}		0.194

Specimen 7a		For total length											
		CUREE cyclic test											
Effective wall length		96in.	2.44m										
cycle	avg. displacement		avg. load		work per cycle		cumulative work		cyclic stiffness		damping ratio	line number
initial	in.	mm	Kips	KN	Kip·ft.	KN·m	Kip·ft.	KN·m	Kip/in.	KN/mm		
	0	0	0	0	0	0	0	0				13
1	0.098	2.487	2.422	10.773	0.014	0.020	0.014	0.020	26.312	4.608	0.115	101
7	0.151	3.832	3.238	14.404	0.026	0.036	0.104	0.141	21.968	3.847	0.102	703
14	0.204	5.171	3.955	17.592	0.042	0.057	0.238	0.322	19.662	3.443	0.099	1401
21	0.415	10.554	6.411	28.515	0.170	0.231	0.556	0.754	15.497	2.714	0.122	2100
25	0.629	15.966	8.198	36.465	0.343	0.466	1.145	1.552	13.082	2.291	0.127	2500
29	0.825	20.954	9.296	41.350	0.498	0.675	2.116	2.868	11.393	1.995	0.123	2900
32	1.208	30.693	10.726	47.710	1.145	1.552	3.774	5.116	9.383	1.643	0.164	3199
35	1.829	46.469	11.830	52.621	1.911	2.590	6.609	8.960	6.644	1.163	0.167	3499
38	2.501	63.525	12.220	54.355	3.534	4.791	11.496	15.586	4.926	0.863	0.222	3798
41	2.388	60.643	8.453	37.599	2.884	3.910	16.342	22.155	3.952	0.692	0.292	4098
44	3.275	83.193	3.312	14.732	0.736	0.998	16.711	22.656	1.016	0.178	0.130	8352
47	2.436	61.883	4.525	20.127	0.873	1.184	11.620	15.754	1.863	0.326	0.152	7545
50	3.228	81.980	3.282	14.597	0.818	1.109	15.975	21.658	1.019	0.178	0.148	8146

cycle	Negative stroke		Positive stroke		Negative stroke		Positive stroke		Area, Kip-in.		Unit load, KN/m	
initial	in.	Kips	in.	Kips	mm	KN	mm	KN	negative	positive	negative	positive
	0	0	0	0	0	0	0	0	0	0	0	0
1	-0.123	-2.477	0.073	2.367	-3.122	-11.017	1.852	10.529	0.152	0.086	-4.518	4.318
7	-0.177	-3.395	0.124	3.081	-4.508	-15.102	3.155	13.705	0.160	0.140	-6.193	5.621
14	-0.233	-4.193	0.174	3.717	-5.913	-18.651	4.430	16.532	0.210	0.171	-7.649	6.780
21	-0.452	-6.654	0.379	6.167	-11.481	-29.598	9.627	27.432	1.189	1.011	-12.138	11.250
25	-0.672	-8.391	0.585	8.005	-17.064	-37.322	14.869	35.607	1.653	1.463	-15.306	14.603
29	-0.928	-9.661	0.721	8.931	-23.581	-42.973	18.326	39.726	2.316	1.153	-17.623	16.292
32	-1.551	-11.790	0.865	9.662	-39.408	-52.441	21.979	42.978	6.683	1.337	-21.506	17.626
35	-2.165	-12.295	1.493	11.365	-55.004	-54.689	37.935	50.554	7.394	6.605	-22.428	20.732
38	-2.678	-11.662	2.324	12.778	-68.011	-51.874	59.040	56.835	6.134	10.030	-21.274	23.308
41	-4.234	-2.868	3.764	7.231	-107.533	-12.757	95.595	32.162	11.305	14.398	-5.232	13.190

		initial	
EEEP Parameters	units	negative	positive
F_{yield}	Kips	-11.007	11.085
	KN	-48.958	49.306
v_{yield}	Kips/ft.	-1.376	1.386
	KN/m	-20.078	20.221
Δ_{yield}	in.	-0.666	0.631
	mm	-16.90	16.02
$\Delta_{failure}$	in.	-3.001	2.987
	mm	-76.22	75.88

Ultimate parameters		units	negative	positive	average
SLS	F_{SLS}	Kips	-12.295	12.778	12.536
		KN	-54.692	56.838	55.765

Specimen 7b	For total length		Specimen 7b	Per unit length	
	CUREE cyclic test			CUREE cyclic test	
Effective wall length	96in.	2.44m	Effective wall length	96in.	2.44m
Date:	Time:		Date:	Time:	
EEEP Parameters	units	initial	EEEP Parameters	units	initial
Peak load, F_{peak}	Kips	10.893	Peak unit load, v_{peak}	Kip/ft.	1.362
	KN	48.451		KN/m	19.870
Drift at peak load, Δ_{peak}	in.	1.848	Drift at capacity, Δ_{peak}	in.	1.848
	mm	46.94		mm	46.94
Yield load, F_{yield}	Kips	9.785	Yield unit load, v_{yield}	Kip/ft.	1.223
	KN	43.524		KN/m	17.849
Drift at yield load, Δ_{yield}	in.	0.519	Drift at yield load, Δ_{yield}	in.	0.519
	mm	13.18		mm	13.18
Proportional limit, $0.4F_{peak}$	Kips	4.357	Proportional limit, $0.4v_{peak}$	Kip/ft.	0.545
	KN	19.380		KN/m	7.948
Drift at prop. limit, $\Delta@0.4F_{peak}$	in.	0.231	Drift at prop. limit, $\Delta@0.4v_{peak}$	in.	0.231
	mm	5.86		mm	5.86
Failure load or $0.8F_{peak}$	Kips	8.714	Unit load at failure or $0.8v_{peak}$	Kip/ft.	1.089
	KN	38.761		KN/m	15.896
Drift at failure, $\Delta_{failure}$	in.	3.033	Drift at failure, $\Delta_{failure}$	in.	3.033
	mm	77.03		mm	77.03
Elastic stiffness, K_e @$0.4F_{peak}$	Kip/in.	18.874	Shear modulus, G @$0.4F_{peak}$	Kip/in.	18.874
	KN/mm	3.305		KN/mm	3.305
Work until failure	Kip·ft.	10.747	Work until failure per unit length	Kip·ft./ft.	1.343
	KN·m	14.570		KN·m/m	5.975
Load @ .32 in. (8.13 mm)	Kips	5.336	Unit load @ .32 in. (8.13 mm)	Kips/ft.	0.667
	KN	23.735		KN/m	9.734
Load @ .48 in. (12.19 mm)	Kips	6.829	Unit load @ .48 in. (12.19 mm)	Kips/ft.	0.854
	KN	30.373		KN/m	12.456
Load @ .96 in. (24.38 mm)	Kips	9.476	Unit load @ .96 in. (24.38 mm)	Kips/ft.	1.185
	KN	42.149		KN/m	17.286
Load @ 1.6 in. (40.64 mm)	Kips	10.817	Unit load @ 1.6 in. (40.64 mm)	Kips/ft.	1.352
	KN	48.113		KN/m	19.732
Ductility factor, μ		5.83	ζ_{eq} @v_{peak}		0.187

		initial	
EEEP Parameters	units	negative	positive
F_{yield}	Kips	-9.598	9.972
	KN	-42.690	44.357
v_{yield}	Kips/ft.	-1.200	1.247
	KN/m	-17.508	18.191
Δ_{yield}	in.	-0.529	0.509
	mm	-13.44	12.92
$\Delta_{failure}$	in.	-3.592	2.474
	mm	-91.24	62.83

Ultimate parameters		units	negative	positive	average
SLS	F_{SLS}	Kips	-10.452	11.333	10.893
		KN	-46.494	50.413	48.454

Specimen 7b		For total length	
		CUREE cyclic test	
Effective wall length		96in.	2.44m

cycle	avg. displacement		avg. load		work per cycle		cumulative work		cyclic stiffness		damping	line
initial	in.	mm	Kips	KN	Kip·ft.	KN·m	Kip·ft.	KN·m	Kip/in.	KN/mm	ratio	number
	0	0	0	0	0	0	0	0				13
1	0.001	0.015	0.133	0.594	0.000	0.000	0.000	0.000	403.579	70.674	0.238	3
7	0.108	2.733	2.634	11.716	0.018	0.024	0.031	0.042	24.491	4.289	0.121	1127
14	0.193	4.903	3.942	17.534	0.044	0.060	0.168	0.227	20.412	3.575	0.111	2528
21	0.397	10.089	6.183	27.501	0.159	0.216	0.478	0.648	15.563	2.725	0.124	3927
25	0.594	15.083	7.716	34.323	0.303	0.411	1.015	1.376	12.992	2.275	0.126	4727
29	0.794	20.178	8.884	39.516	0.464	0.630	1.915	2.596	11.185	1.959	0.126	5527
32	1.324	33.640	10.738	47.763	1.357	1.840	3.716	5.037	8.132	1.424	0.182	6127
35	1.848	46.937	10.893	48.451	1.972	2.674	6.623	8.980	5.895	1.032	0.187	6727
38	2.421	61.501	9.083	40.403	2.798	3.794	10.747	14.570	3.807	0.667	0.239	7327
41	3.440	87.366	6.940	30.871	2.721	3.688	15.157	20.550	2.001	0.350	0.215	7928
44	0.319	8.092	0.449	1.997	0.022	0.030	16.733	22.685	1.258	0.220	0.260	8551

cycle	Negative stroke		Positive stroke		Negative stroke		Positive stroke		Area, Kip-in.		Unit load, KN/m	
initial	in.	Kips	in.	Kips	mm	KN	mm	KN	negative	positive	negative	positive
	0	0	0	0	0	0	0	0	0	0	0	0
1	0.001	0.132	0.000	0.135	0.025	0.587	0.005	0.601	0.000	0.000	0.241	0.246
7	-0.109	-2.557	0.106	2.711	-2.764	-11.375	2.703	12.058	0.133	0.151	-4.665	4.945
14	-0.191	-3.744	0.195	4.140	-4.862	-16.653	4.945	18.415	0.260	0.302	-6.829	7.552
21	-0.393	-5.998	0.401	6.368	-9.982	-26.677	10.196	28.326	0.982	1.086	-10.940	11.616
25	-0.581	-7.459	0.607	7.974	-14.757	-33.176	15.408	35.470	1.265	1.472	-13.606	14.546
29	-0.763	-8.570	0.826	9.198	-19.370	-38.120	20.985	40.911	1.455	1.885	-15.633	16.778
32	-1.220	-10.294	1.428	11.182	-31.001	-45.790	36.279	49.737	4.319	6.135	-18.779	20.397
35	-1.853	-10.452	1.842	11.333	-47.076	-46.492	46.797	50.411	6.565	4.662	-19.067	20.674
38	-2.842	-9.907	3.320	6.028	-72.194	-44.066	84.328	26.815	10.067	12.827	-18.072	10.997
41	-3.616	-8.422	4.424	4.138	-91.844	-37.461	112.382	18.408	7.090	5.615	-15.363	7.549
44	-0.275	-0.040	0.362	0.858	-6.993	-0.180	9.192	3.815	-14.135	-10.148	-0.074	1.564

Specimen 8a	For total length		Specimen 8a	Per unit length	
	CUREE cyclic test			CUREE cyclic test	
Effective wall length	96in.	2.44m	Effective wall length	96in.	2.44m
Date:	Time:		Date:	Time:	
EEEP Parameters	units	initial	EEEP Parameters	units	initial
Peak load, F_{peak}	Kips	15.389	Peak unit load, v_{peak}	Kip/ft.	1.924
	KN	68.449		KN/m	28.071
Drift at peak load, Δ_{peak}	in.	2.122	Drift at capacity, Δ_{peak}	in.	2.122
	mm	53.90		mm	53.90
Yield load, F_{yield}	Kips	13.904	Yield unit load, v_{yield}	Kip/ft.	1.738
	KN	61.847		KN/m	25.364
Drift at yield load, Δ_{yield}	in.	0.674	Drift at yield load, Δ_{yield}	in.	0.674
	mm	17.12		mm	17.12
Proportional limit, $0.4F_{peak}$	Kips	6.155	Proportional limit, $0.4v_{peak}$	Kip/ft.	0.769
	KN	27.379		KN/m	11.228
Drift at prop. limit, $\Delta@0.4F_{peak}$	in.	0.298	Drift at prop. limit, $\Delta@0.4v_{peak}$	in.	0.298
	mm	7.57		mm	7.57
Failure load or $0.8F_{peak}$	Kips	12.314	Unit load at failure or $0.8v_{peak}$	Kip/ft.	1.539
	KN	54.774		KN/m	22.463
Drift at failure, $\Delta_{failure}$	in.	3.244	Drift at failure, $\Delta_{failure}$	in.	3.244
	mm	82.39		mm	82.39
Elastic stiffness, K_e @$0.4F_{peak}$	Kip/in.	21.098	Shear modulus, G @$0.4F_{peak}$	Kip/in	21.098
	KN/mm	3.695		KN/mm	3.695
Work until failure	Kip·ft.	19.305	Work until failure per unit length	Kip·ft./ft.	2.413
	KN·m	26.173		KN·m/m	10.734
Load @ .32 in. (8.13 mm)	Kips	6.493	Unit load @ .32 in. (8.13 mm)	Kips/ft.	0.812
	KN	28.880		KN/m	11.844
Load @ .48 in. (12.19 mm)	Kips	8.495	Unit load @ .48 in. (12.19 mm)	Kips/ft.	1.062
	KN	37.786		KN/m	15.496
Load @ .96 in. (24.38 mm)	Kips	12.615	Unit load @ .96 in. (24.38 mm)	Kips/ft.	1.577
	KN	56.113		KN/m	23.012
Load @ 1.6 in. (40.64 mm)	Kips	14.972	Unit load @ 1.6 in. (40.64 mm)	Kips/ft.	1.872
	KN	66.596		KN/m	27.311
Ductility factor, μ		4.85	$\zeta_{eq}@v_{peak}$		0.191

		initial	
EEEP Parameters	units	negative	positive
F_{yield}	Kips	-13.390	14.419
	KN	-59.557	64.137
v_{yield}	Kips/ft.	-1.674	1.802
	KN/m	-24.425	26.303
Δ_{yield}	in.	-0.561	0.787
	mm	-14.24	20.00
$\Delta_{failure}$	in.	-2.845	3.642
	mm	-72.26	92.52

Ultimate parameters		units	negative	positive	average
SLS	F_{SLS}	Kips	-14.910	15.868	15.389
		KN	-66.322	70.582	68.452

Specimen 8a	For total length	
	CUREE cyclic test	
Effective wall length	96in.	2.44m

cycle	avg. displacement		avg. load		work per cycle		cumulative work		cyclic stiffness		damping	line
initial	in.	mm	Kips	KN	Kip·ft.	KN·m	Kip·ft.	KN·m	Kip/in.	KN/mm	ratio	number
	0	0	0	0	0	0	0	0				13
1	0.062	1.563	2.289	10.180	0.013	0.017	0.013	0.017	37.420	6.553	0.171	124
7	0.102	2.597	3.156	14.040	0.024	0.032	0.092	0.125	31.229	5.469	0.139	876
14	0.140	3.564	3.837	17.066	0.038	0.052	0.210	0.285	27.869	4.880	0.134	1751
21	0.303	7.701	6.226	27.691	0.135	0.183	0.472	0.639	21.003	3.678	0.136	2625
25	0.473	12.022	8.447	37.570	0.260	0.353	0.922	1.250	18.157	3.180	0.124	3124
29	0.653	16.587	10.383	46.185	0.418	0.566	1.695	2.298	16.120	2.823	0.117	3624
32	1.175	29.835	14.066	62.564	1.409	1.910	3.477	4.714	12.101	2.119	0.162	3999
35	1.773	45.046	15.286	67.991	2.339	3.172	6.780	9.193	8.658	1.516	0.164	4374
38	2.400	60.968	15.220	67.700	4.186	5.675	12.595	17.075	6.367	1.115	0.218	4749
41	3.470	88.133	11.405	50.730	4.216	5.715	19.305	26.173	3.277	0.574	0.202	5124

cycle	Negative stroke		Positive stroke		Negative stroke		Positive stroke		Area, Kip-in.		Unit load, KN/m	
initial	in.	Kips	in.	Kips	mm	KN	mm	KN	negative	positive	negative	positive
	0	0	0	0	0	0	0	0	0	0	0	0
1	-0.053	-2.093	0.070	2.485	-1.356	-9.308	1.770	11.053	0.056	0.087	-3.817	4.533
7	-0.087	-2.912	0.118	3.400	-2.202	-12.954	2.992	15.125	0.083	0.142	-5.313	6.203
14	-0.116	-3.574	0.165	4.100	-2.941	-15.895	4.186	18.236	0.094	0.176	-6.519	7.479
21	-0.252	-6.013	0.354	6.438	-6.413	-26.746	8.989	28.637	0.655	0.996	-10.969	11.744
25	-0.402	-8.122	0.545	8.771	-10.206	-36.128	13.838	39.012	1.055	1.452	-14.816	15.999
29	-0.562	-9.941	0.744	10.826	-14.270	-44.216	18.905	48.153	1.445	1.955	-18.133	19.748
32	-1.030	-13.521	1.319	14.611	-26.165	-60.139	33.505	64.988	5.493	7.310	-24.663	26.652
35	-1.630	-14.910	1.916	15.662	-41.412	-66.318	48.679	69.663	8.533	9.042	-27.198	28.569
38	-2.187	-14.573	2.614	15.868	-55.547	-64.822	66.388	70.579	8.204	10.991	-26.584	28.945
41	-3.297	-10.110	3.642	12.701	-83.746	-44.968	92.519	56.493	13.701	14.695	-18.442	23.168

Specimen 8b	For total length		Specimen 8b	Per unit length	
	CUREE cyclic test			CUREE cyclic test	
Effective wall length	96in.	2.44m	Effective wall length	96in.	2.44m
Date:	Time:		Date:	Time:	
EEEP Parameters	units	initial	EEEP Parameters	units	initial
Peak load, F_{peak}	Kips	15.520	Peak unit load, v_{peak}	Kip/ft.	1.940
	KN	69.032		KN/m	28.310
Drift at peak load, Δ_{peak}	in.	2.897	Drift at capacity, Δ_{peak}	in.	2.897
	mm	73.59		mm	73.59
Yield load, F_{yield}	Kips	13.467	Yield unit load, v_{yield}	Kip/ft.	1.683
	KN	59.899		KN/m	24.565
Drift at yield load, Δ_{yield}	in.	0.655	Drift at yield load, Δ_{yield}	in.	0.655
	mm	16.63		mm	16.63
Proportional limit, $0.4F_{peak}$	Kips	6.208	Proportional limit, $0.4v_{peak}$	Kip/ft.	0.776
	KN	27.613		KN/m	11.324
Drift at prop. limit, $\Delta@0.4F_{peak}$	in.	0.302	Drift at prop. limit, $\Delta@0.4v_{peak}$	in.	0.302
	mm	7.67		mm	7.67
Failure load or $0.8F_{peak}$	Kips	15.520	Unit load at failure or $0.8v_{peak}$	Kip/ft.	1.940
	KN	69.032		KN/m	28.310
Drift at failure, $\Delta_{failure}$	in.	2.897	Drift at failure, $\Delta_{failure}$	in.	2.897
	mm	73.59		mm	73.59
Elastic stiffness, K_e @$0.4F_{peak}$	Kip/in.	20.630	Shear modulus, G @$0.4F_{peak}$	Kip/in.	20.630
	KN/mm	3.613		KN/mm	3.613
Work until failure	Kip·ft.	13.999	Work until failure per unit length	Kip·ft./ft.	1.750
	KN·m	18.979		KN·m/m	7.783
Load @ .32 in. (8.13 mm)	Kips	6.451	Unit load @ .32 in. (8.13 mm)	Kips/ft.	0.806
	KN	28.692		KN/m	11.767
Load @ .48 in. (12.19 mm)	Kips	8.102	Unit load @ .48 in. (12.19 mm)	Kips/ft.	1.013
	KN	36.037		KN/m	14.779
Load @ .96 in. (24.38 mm)	Kips	11.347	Unit load @ .96 in. (24.38 mm)	Kips/ft.	1.418
	KN	50.472		KN/m	20.699
Load @ 1.6 in. (40.64 mm)	Kips	13.753	Unit load @ 1.6 in. (40.64 mm)	Kips/ft.	1.719
	KN	61.175		KN/m	25.088
Ductility factor, μ		4.43	ζ_{eq}@v_{peak}		0.184

		initial	
EEEP Parameters	units	negative	positive
F_{yield}	Kips	-12.905	14.028
	KN	-57.402	62.396
v_{yield}	Kips/ft	-1.613	1.753
	KN/m	-23.541	25.589
Δ_{yield}	in.	-0.603	0.706
	mm	-15.32	17.93
$\Delta_{failure}$	in.	-2.747	3.987
	mm	-69.76	101.27

Ultimate parameters		units	negative	positive	average
SLS	F_{SLS}	Kips	-14.579	16.461	15.520
		KN	-64.850	73.221	69.035

Specimen 8b		For total length	
		CUREE cyclic test	
Effective wall length		96in.	2.44m

cycle	avg. displacement		avg. load		work per cycle		cumulative work		cyclic stiffness		damping	line
initial	in.	mm	Kips	KN	Kip·ft.	KN·m	Kip·ft.	KN·m	Kip/in.	KN/mm	ratio	number
	0	0	0	0	0	0	0	0				13
1	0.088	2.233	2.821	12.546	0.016	0.022	0.016	0.022	34.359	6.017	0.122	109
7	0.134	3.409	3.896	17.328	0.031	0.042	0.124	0.168	29.027	5.083	0.113	773
14	0.182	4.622	4.720	20.996	0.052	0.070	0.287	0.390	25.945	4.543	0.115	1551
21	0.367	9.314	7.023	31.237	0.202	0.274	0.664	0.901	19.175	3.358	0.149	2328
25	0.561	14.237	8.884	39.516	0.364	0.493	1.322	1.793	15.857	2.777	0.139	2773
29	0.759	19.285	10.344	46.011	0.540	0.733	2.394	3.245	13.642	2.389	0.131	3217
32	1.352	34.351	13.229	58.841	1.556	2.109	4.467	6.056	9.812	1.718	0.166	3550
35	1.997	50.719	14.676	65.279	2.382	3.229	7.936	10.759	7.349	1.287	0.155	3883
38	2.897	73.586	15.520	69.032	4.348	5.894	13.999	18.979	5.355	0.938	0.184	4217
41	3.498	88.852	14.602	64.949	4.814	6.526	19.079	25.867	4.180	0.732	0.180	8199

cycle	Negative stroke		Positive stroke		Negative stroke		Positive stroke		Area, Kip-in.		Unit load, KN/m	
initial	in.	Kips	in.	Kips	mm	KN	mm	KN	negative	positive	negative	positive
	0	0	0	0	0	0	0	0	0	0	0	0
1	-0.112	-2.928	0.064	2.714	-2.847	-13.023	1.618	12.070	0.164	0.086	-5.341	4.950
7	-0.132	-3.803	0.137	3.988	-3.340	-16.917	3.477	17.739	0.065	0.245	-6.938	7.275
14	-0.175	-4.556	0.189	4.884	-4.453	-20.266	4.790	21.726	0.183	0.229	-8.311	8.910
21	-0.347	-6.804	0.387	7.242	-8.809	-30.262	9.820	32.211	0.974	1.200	-12.411	13.210
25	-0.533	-8.518	0.588	9.250	-13.531	-37.888	14.943	41.143	1.424	1.663	-15.538	16.873
29	-0.717	-10.009	0.801	10.679	-18.214	-44.522	20.356	47.500	1.708	2.123	-18.259	19.480
32	-1.258	-12.904	1.447	13.553	-31.958	-57.398	36.744	60.284	6.199	7.817	-23.539	24.723
35	-1.936	-14.179	2.058	15.174	-49.164	-63.066	52.273	67.492	9.173	8.782	-25.864	27.679
38	-2.747	-14.579	3.048	16.461	-69.764	-64.847	77.409	73.217	11.661	15.653	-26.594	30.027
41			3.987	15.875								

Specimen 9a	For total length		Specimen 9a	Per unit length	
	CUREE cyclic test			CUREE cyclic test	
Effective wall length	96in.	2.44m	Effective wall length	96in.	2.44m
Date:	Time:		Date:	Time:	
EEEP Parameters	units	initial	EEEP Parameters	units	initial
Peak load, F_{peak}	Kips	14.892	Peak unit load, v_{peak}	Kip/ft.	1.862
	KN	66.240		KN/m	27.166
Drift at peak load, Δ_{peak}	in.	2.210	Drift at capacity, Δ_{peak}	in.	2.210
	mm	56.14		mm	56.14
Yield load, F_{yield}	Kips	13.004	Yield unit load, v_{yield}	Kip/ft.	1.626
	KN	57.843		KN/m	23.722
Drift at yield load, Δ_{yield}	in.	0.735	Drift at yield load, Δ_{yield}	in.	0.735
	mm	18.67		mm	18.67
Proportional limit, $0.4F_{peak}$	Kips	5.957	Proportional limit, $0.4v_{peak}$	Kip/ft.	0.745
	KN	26.496		KN/m	10.866
Drift at prop. limit, $\Delta @0.4F_{peak}$	in.	0.337	Drift at prop. limit, $\Delta @0.4v_{peak}$	in.	0.337
	mm	8.56		mm	8.56
Failure load or $0.8F_{peak}$	Kips	13.443	Unit load at failure or $0.8v_{peak}$	Kip/ft.	1.680
	KN	59.794		KN/m	24.522
Drift at failure, $\Delta_{failure}$	in.	2.733	Drift at failure, $\Delta_{failure}$	in.	2.733
	mm	69.42		mm	69.42
Elastic stiffness, K_e $@0.4F_{peak}$	Kip/in.	17.694	Shear modulus, G $@0.4F_{peak}$	Kip/in.	17.694
	KN/mm	3.099		KN/mm	3.099
Work until failure	Kip·ft.	10.225	Work until failure per unit length	Kip·ft./ft.	1.278
	KN·m	13.863		KN·m/m	5.685
Load @ .32 in. (8.13 mm)	Kips	5.757	Unit load @ .32 in. (8.13 mm)	Kips/ft.	0.720
	KN	25.607		KN/m	10.502
Load @ .48 in. (12.19 mm)	Kips	7.509	Unit load @ .48 in. (12.19 mm)	Kips/ft.	0.939
	KN	33.401		KN/m	13.698
Load @ .96 in. (24.38 mm)	Kips	11.062	Unit load @ .96 in. (24.38 mm)	Kips/ft.	1.383
	KN	49.202		KN/m	20.178
Load @ 1.6 in. (40.64 mm)	Kips	13.988	Unit load @ 1.6 in. (40.64 mm)	Kips/ft.	1.748
	KN	62.217		KN/m	25.515
Ductility factor, μ		3.72	$\zeta_{eq} @v_{peak}$		0.159

		initial	
EEEP Parameters	units	negative	positive
F_{yield}	Kips	-13.606	12.403
	KN	-60.518	55.167
v_{yield}	Kips/ft.	-1.701	1.550
	KN/m	-24.819	22.624
Δ_{yield}	in.	-0.736	0.733
	mm	-18.70	18.63
$\Delta_{failure}$	in.	-2.454	3.012
	mm	-62.33	76.51

Ultimate parameters		units	negative	positive	average
SLS	F_{SLS}	Kips	-15.291	15.213	15.252
		KN	-68.018	67.669	67.844

Specimen 9a	For total length	
	CUREE cyclic test	
Effective wall length	96in.	2.44m

cycle	avg. displacement		avg. load		work per cycle		cumulative work		cyclic stiffness		damping ratio	line number
initial	in.	mm	Kips	KN	Kip·ft.	KN·m	Kip·ft.	KN·m	Kip/in.	KN/mm		
	0	0	0	0	0	0	0	0				13
1	0.059	1.494	1.804	8.024	0.008	0.011	0.008	0.011	30.732	5.382	0.149	109
7	0.099	2.515	2.587	11.507	0.019	0.025	0.066	0.089	26.215	4.591	0.139	778
14	0.141	3.573	3.293	14.646	0.031	0.041	0.156	0.211	23.499	4.115	0.126	1554
21	0.310	7.865	5.632	25.050	0.117	0.159	0.376	0.510	18.271	3.200	0.129	2331
25	0.488	12.395	7.571	33.677	0.244	0.330	0.799	1.083	15.627	2.736	0.126	2775
29	0.669	16.989	9.207	40.952	0.377	0.511	1.522	2.063	13.888	2.432	0.117	3219
32	1.242	31.552	12.721	56.581	1.219	1.653	3.105	4.210	10.341	1.811	0.148	3552
35	1.815	46.107	14.684	65.315	1.988	2.695	5.926	8.034	8.155	1.428	0.143	3885
38	2.122	53.900	15.056	66.968	2.941	3.988	10.225	13.863	7.139	1.250	0.176	4220
41	2.894	73.505	13.403	59.618	3.497	4.741	15.237	20.658	4.843	0.848	0.176	4554

cycle	Negative stroke		Positive stroke		Negative stroke		Positive stroke		Area, Kip-in.		Unit load, KN/m	
initial	in.	Kips	in.	Kips	mm	KN	mm	KN	negative	positive	negative	positive
	0	0	0	0	0	0	0	0	0	0	0	0
1	-0.061	-1.766	0.057	1.842	-1.542	-7.854	1.445	8.193	0.054	0.052	-3.221	3.360
7	-0.093	-2.566	0.105	2.608	-2.362	-11.416	2.667	11.599	0.070	0.107	-4.682	4.757
14	-0.132	-3.281	0.149	3.305	-3.348	-14.594	3.797	14.699	0.113	0.132	-5.985	6.028
21	-0.287	-5.565	0.333	5.699	-7.285	-24.753	8.446	25.347	0.686	0.824	-10.151	10.395
25	-0.446	-7.551	0.530	7.592	-11.331	-33.586	13.459	33.769	1.045	1.312	-13.774	13.849
29	-0.607	-9.232	0.731	9.182	-15.415	-41.063	18.562	40.842	1.349	1.685	-16.840	16.749
32	-1.126	-12.864	1.358	12.578	-28.611	-57.217	34.493	55.946	5.739	6.824	-23.465	22.944
35	-1.664	-14.875	1.967	14.493	-42.263	-66.163	49.952	64.466	7.455	8.238	-27.134	26.438
38	-1.943	-14.899	3.092	11.374	-49.355	-66.270	78.532	50.589	4.156	14.553	-27.177	20.747
41	-2.454	-15.291	3.334	11.515	-62.334	-68.015	84.676	51.221	7.714	2.768	-27.893	21.006

Specimen 9b	For total length		Specimen 9b	Per unit length	
	CUREE cyclic test			CUREE cyclic test	
Effective wall length	96in.	2.44m	Effective wall length	96in.	2.44m
Date:	Time:		Date:	Time:	
EEEP Parameters	units	initial	EEEP Parameters	units	initial
Peak load, F_{peak}	Kips	16.647	Peak unit load, v_{peak}	Kip/ft.	2.081
	KN	74.048		KN/m	30.367
Drift at peak load, Δ_{peak}	in.	2.686	Drift at capacity, Δ_{peak}	in.	2.686
	mm	68.24		mm	68.24
Yield load, F_{yield}	Kips	14.721	Yield unit load, v_{yield}	Kip/ft.	1.840
	KN	65.480		KN/m	26.854
Drift at yield load, Δ_{yield}	in.	0.945	Drift at yield load, Δ_{yield}	in.	0.945
	mm	24.01		mm	24.01
Proportional limit, $0.4F_{peak}$	Kips	6.659	Proportional limit, $0.4v_{peak}$	Kip/ft.	0.832
	KN	29.619		KN/m	12.147
Drift at prop. limit, $\Delta@0.4F_{peak}$	in.	0.427	Drift at prop. limit, $\Delta@0.4v_{peak}$	in.	0.427
	mm	10.86		mm	10.86
Failure load or $0.8F_{peak}$	Kips	14.602	Unit load at failure or $0.8v_{peak}$	Kip/ft.	1.825
	KN	64.949		KN/m	26.636
Drift at failure, $\Delta_{failure}$	in.	3.498	Drift at failure, $\Delta_{failure}$	in.	3.498
	mm	88.85		mm	88.85
Elastic stiffness, K_e @$0.4F_{peak}$	Kip/in	15.577	Shear modulus, G @$0.4F_{peak}$	Kip/in	15.577
	KN/mm	2.728		KN/mm	2.728
Work until failure	Kip·ft.	19.079	Work until failure per unit length	Kip·ft./ft.	2.385
	KN·m	25.867		KN·m/m	10.608
Load @ .32 in. (8.13 mm)	Kips	5.410	Unit load @ .32 in. (8.13 mm)	Kips/ft.	0.676
	KN	24.062		KN/m	9.868
Load @ .48 in. (12.19 mm)	Kips	7.220	Unit load @ .48 in. (12.19 mm)	Kips/ft.	0.903
	KN	32.116		KN/m	13.171
Load @ .96 in. (24.38 mm)	Kips	11.081	Unit load @ .96 in. (24.38 mm)	Kips/ft.	1.385
	KN	49.289		KN/m	20.213
Load @ 1.6 in. (40.64 mm)	Kips	14.366	Unit load @ 1.6 in. (40.64 mm)	Kips/ft.	1.796
	KN	63.902		KN/m	26.207
Ductility factor, μ		3.70	$\zeta_{eq}@v_{peak}$		0.177

		initial	
EEEP Parameters	units	negative	positive
F_{yield}	Kips	-14.707	14.736
	KN	-65.416	65.544
v_{yield}	Kips/ft.	-1.838	1.842
	KN/m	-26.827	26.880
Δ_{yield}	in.	-0.950	0.940
	mm	-24.14	23.88
$\Delta_{failure}$	in.	-3.600	3.396
	mm	-91.44	86.26

Ultimate parameters		units	negative	positive	average
SLS	F_{SLS}	Kips	-16.611	16.684	16.647
		KN	-73.887	74.216	74.051

Specimen 9b	For total length	
	CUREE cyclic test	
Effective wall length	96in.	2.44m

cycle	avg. displacement		avg. load		work per cycle		cumulative work		cyclic stiffness		damping ratio	line number
initial	in.	mm	Kips	KN	Kip·ft.	KN·m	Kip·ft.	KN·m	Kip/in.	KN/mm		
	0	0	0	0	0	0	0	0				13
1	0.087	2.215	2.192	9.751	0.013	0.018	0.013	0.018	25.383	4.445	0.135	197
7	0.135	3.437	3.018	13.426	0.025	0.034	0.098	0.133	22.329	3.910	0.117	1400
14	0.184	4.666	3.676	16.353	0.041	0.055	0.226	0.307	20.016	3.505	0.115	2799
21	0.368	9.351	6.021	26.781	0.136	0.184	0.509	0.690	16.355	2.864	0.117	4198
25	0.543	13.780	7.884	35.068	0.250	0.338	0.960	1.302	14.537	2.546	0.111	4998
29	0.737	18.720	9.616	42.772	0.393	0.533	1.707	2.314	13.071	2.289	0.106	5797
32	1.316	33.421	13.350	59.380	1.307	1.772	3.379	4.581	10.177	1.782	0.142	6397
35	1.897	48.186	15.429	68.628	2.137	2.898	6.384	8.655	8.141	1.426	0.139	6998
38	2.686	68.236	16.647	74.048	4.154	5.632	11.951	16.203	6.201	1.086	0.177	7598
41	3.498	88.852	14.602	64.949	4.814	6.526	19.079	25.867	4.180	0.732	0.180	8199

cycle	Negative stroke		Positive stroke		Negative stroke		Positive stroke		Area, Kip-in.		Unit load, KN/m	
initial	in.	Kips	in.	Kips	mm	KN	mm	KN	negative	positive	negative	positive
	0	0	0	0	0	0	0	0	0	0	0	0
1	-0.096	-2.197	0.079	2.188	-2.433	-9.772	1.996	9.731	0.105	0.086	-4.007	3.991
7	-0.138	-2.962	0.132	3.075	-3.510	-13.177	3.363	13.675	0.109	0.142	-5.404	5.608
14	-0.185	-3.650	0.182	3.703	-4.712	-16.235	4.620	16.471	0.156	0.168	-6.658	6.755
21	-0.359	-5.868	0.378	6.174	-9.106	-26.103	9.596	27.460	0.823	0.967	-10.705	11.261
25	-0.523	-7.669	0.562	8.099	-13.279	-34.112	14.280	36.023	1.112	1.316	-13.990	14.773
29	-0.694	-9.344	0.780	9.888	-17.617	-41.562	19.822	43.983	1.453	1.962	-17.045	18.038
32	-1.225	-13.022	1.406	13.678	-31.125	-57.921	35.717	60.839	5.947	7.374	-23.754	24.950
35	-1.815	-15.130	1.980	15.727	-46.091	-67.300	50.282	69.955	8.294	8.430	-27.600	28.689
38	-2.615	-16.611	2.758	16.684	-66.413	-73.884	70.058	74.212	12.698	12.618	-30.300	30.435
41	-3.600	-14.363	3.396	14.841	-91.440	-63.888	86.263	66.011	15.259	10.056	-26.201	27.071

Specimen 10a	For total length		Specimen 10a	Per unit length	
	CUREE cyclic test			CUREE cyclic test	
Effective wall length	96in.	2.44m	Effective wall length	96in.	2.44m
Date:	Time:		Date:	Time:	
EEEP Parameters	units	initial	EEEP Parameters	units	initial
Peak load, F_{peak}	Kips	7.473	Peak unit load, v_{peak}	Kip/ft.	0.934
	KN	33.241		KN/m	13.632
Drift at peak load, Δ_{peak}	in.	3.552	Drift at capacity, Δ_{peak}	in.	3.552
	mm	90.21		mm	90.21
Yield load, F_{yield}	Kips	6.316	Yield unit load, v_{yield}	Kip/ft.	0.789
	KN	28.092		KN/m	11.521
Drift at yield load, Δ_{yield}	in.	1.322	Drift at yield load, Δ_{yield}	in.	1.322
	mm	33.58		mm	33.58
Proportional limit,	Kips	2.989	Proportional limit,	Kip/ft.	0.374
$0.4F_{peak}$	KN	13.296	$0.4v_{peak}$	KN/m	5.453
Drift at prop. limit,	in.	0.626	Drift at prop. limit,	in.	0.626
$\Delta@0.4F_{peak}$	mm	15.89	$\Delta@0.4v_{peak}$	mm	15.89
Failure load or $0.8F_{peak}$	Kips	7.460	Unit load at failure or	Kip/ft.	0.933
	KN	33.184	$0.8v_{peak}$	KN/m	13.609
Drift at failure, $\Delta_{failure}$	in.	3.697	Drift at failure, $\Delta_{failure}$	in.	3.697
	mm	93.91		mm	93.91
Elastic stiffness, K_e	Kip/in.	4.777	Shear modulus, G	Kip/in.	4.777
$@0.4F_{peak}$	KN/mm	0.837	$@0.4F_{peak}$	KN/mm	0.837
Work until failure	Kip·ft.	7.604	Work until failure per	Kip·ft./ft.	0.951
	KN·m	10.310	unit length	KN·m/m	4.228
Load @ .32 in.	Kips	1.873	Unit load @ .32 in.	Kips/ft	0.234
(8.13 mm)	KN	8.331	(8.13 mm)	KN/m	3.417
Load @ .48 in.	Kips	2.487	Unit load @ .48 in.	Kips/ft	0.311
(12.19 mm)	KN	11.061	(12.19 mm)	KN/m	4.536
Load @ .96 in.	Kips	3.903	Unit load @ .96 in.	Kips/ft	0.488
(24.38 mm)	KN	17.360	(24.38 mm)	KN/m	7.120
Load @ 1.6 in.	Kips	5.316	Unit load @ 1.6 in.	Kips/ft	0.664
(40.64 mm)	KN	23.645	(40.64 mm)	KN/m	9.697
Ductility factor, μ		2.79	ζ_{eq} $@v_{peak}$		0.142

		initial	
EEEP Parameters	units	negative	positive
F_{yield}	Kips	-5.934	6.697
	KN	-26.394	29.789
v_{yield}	Kips/ft.	-0.742	0.837
	KN/m	-10.824	12.217
Δ_{yield}	in.	-1.243	1.401
	mm	-31.57	35.58
$\Delta_{failure}$	in.	-3.311	4.083
	mm	-84.10	103.72

Ultimate parameters		units	negative	positive	average
SLS	F_{SLS}	Kips	-7.006	7.941	7.473
		KN	-31.163	35.322	33.242

Specimen 10a		For total length	
		CUREE cyclic test	
Effective wall length		96in.	2.44m

cycle	avg. displacement		avg. load		work per cycle		cumulative work		cyclic stiffness		damping ratio	line number
initial	in.	mm	Kips	KN	Kip·ft.	KN·m	Kip·ft.	KN·m	Kip/in.	KN/mm		
	0	0	0	0	0	0	0	0				13
1	0.098	2.479	0.810	3.604	0.004	0.006	0.004	0.006	8.299	1.453	0.098	112
7	0.151	3.846	1.132	5.037	0.008	0.011	0.031	0.042	7.471	1.308	0.089	781
14	0.203	5.150	1.390	6.183	0.013	0.017	0.070	0.095	6.850	1.200	0.087	1558
21	0.410	10.408	2.241	9.968	0.047	0.064	0.161	0.218	5.467	0.957	0.098	2336
25	0.613	15.557	2.950	13.121	0.094	0.127	0.323	0.438	4.815	0.843	0.099	2781
29	0.819	20.808	3.574	15.899	0.146	0.198	0.600	0.814	4.362	0.764	0.095	3225
32	1.458	37.029	5.065	22.528	0.466	0.631	1.208	1.638	3.473	0.608	0.120	3559
35	2.051	52.104	6.105	27.154	0.786	1.066	2.332	3.161	2.976	0.521	0.120	3892
38	3.071	78.007	7.208	32.063	1.580	2.143	4.475	6.067	2.347	0.411	0.136	4226
41	3.697	93.911	7.460	33.184	2.143	2.906	7.604	10.310	2.026	0.355	0.147	4560
44	0.299	7.601	0.723	3.214	0.034	0.046	22.060	29.908	2.102	0.368	0.248	8808

cycle	Negative stroke		Positive stroke		Negative stroke		Positive stroke		Area, Kip-in.		Unit load, KN/m	
initial	in.	Kips	in.	Kips	mm	KN	mm	KN	negative	positive	negative	positive
	0	0	0	0	0	0	0	0	0	0	0	0
1	-0.097	-0.770	0.098	0.851	-2.461	-3.423	2.497	3.785	0.037	0.042	-1.404	1.552
7	-0.147	-1.052	0.156	1.213	-3.736	-4.678	3.955	5.396	0.046	0.059	-1.919	2.213
14	-0.199	-1.293	0.206	1.487	-5.067	-5.750	5.232	6.616	0.061	0.068	-2.358	2.713
21	-0.400	-2.148	0.419	2.334	-10.170	-9.552	10.645	10.383	0.346	0.407	-3.917	4.258
25	-0.596	-2.835	0.629	3.065	-15.146	-12.610	15.969	13.632	0.488	0.566	-5.171	5.591
29	-0.802	-3.436	0.836	3.712	-20.378	-15.285	21.237	16.513	0.646	0.703	-6.268	6.772
32	-1.422	-4.883	1.494	5.247	-36.109	-21.719	37.950	23.337	2.576	2.948	-8.907	9.571
35	-2.004	-5.936	2.098	6.274	-50.909	-26.402	53.299	27.906	3.152	3.481	-10.827	11.444
38	-3.020	-7.006	3.122	7.411	-76.703	-31.162	79.311	32.964	6.571	7.007	-12.780	13.519
41	-3.311	-6.980	4.083	7.941	-84.104	-31.048	103.718	35.320	2.038	7.376	-12.733	14.485

Specimen 10b	For total length		Specimen 10b	Per unit length	
	CUREE cyclic test			CUREE cyclic test	
Effective wall length	96in.	2.44m	Effective wall length	96in.	2.44m
Date:	Time:		Date:	Time:	
EEEP Parameters	units	initial	EEEP Parameters	units	initial
Peak load, F_{peak}	Kips	6.976	Peak unit load, v_{peak}	Kip/ft.	0.872
	KN	31.031		KN/m	12.726
Drift at peak load, Δ_{peak}	in.	2.873	Drift at capacity, Δ_{peak}	in.	2.873
	mm	72.97		mm	72.97
Yield load, F_{yield}	Kips	5.929	Yield unit load, v_{yield}	Kip/ft.	0.741
	KN	26.373		KN/m	10.816
Drift at yield load, Δ_{yield}	in.	0.924	Drift at yield load, Δ_{yield}	in.	0.924
	mm	23.48		mm	23.48
Proportional limit, $0.4F_{peak}$	Kips	2.791	Proportional limit, $0.4v_{peak}$	Kip/ft.	0.349
	KN	12.412		KN/m	5.090
Drift at prop. limit, $\Delta@0.4F_{peak}$	in.	0.435	Drift at prop. limit, $\Delta@0.4v_{peak}$	in.	0.435
	mm	11.04		mm	11.04
Failure load or $0.8F_{peak}$	Kips	6.200	Unit load at failure or $0.8v_{peak}$	Kip/ft.	0.775
	KN	27.576		KN/m	11.309
Drift at failure, $\Delta_{failure}$	in.	3.700	Drift at failure, $\Delta_{failure}$	in.	3.700
	mm	93.98		mm	93.98
Elastic stiffness, K_e @$0.4F_{peak}$	Kip/in.	6.413	Shear modulus, G @$0.4F_{peak}$	Kip/in	6.413
	KN/mm	1.123		KN/mm	1.123
Work until failure	Kip·ft.	8.190	Work until failure per unit length	Kip·ft./ft.	1.024
	KN·m	11.104		KN·m/m	4.554
Load @ .32 in. (8.13 mm)	Kips	2.293	Unit load @ .32 in. (8.13 mm)	Kips/ft.	0.287
	KN	10.201		KN/m	4.184
Load @ .48 in. (12.19 mm)	Kips	2.942	Unit load @ .48 in. (12.19 mm)	Kips/ft.	0.368
	KN	13.084		KN/m	5.366
Load @ .96 in. (24.38 mm)	Kips	4.254	Unit load @ .96 in. (24.38 mm)	Kips/ft.	0.532
	KN	18.922		KN/m	7.760
Load @ 1.6 in. (40.64 mm)	Kips	5.525	Unit load @ 1.6 in. (40.64 mm)	Kips/ft.	0.691
	KN	24.577		KN/m	10.079
Ductility factor, μ		4.01	ζ_{eq} @v_{peak}		0.156

		initial	
EEEP Parameters	units	negative	positive
F_{yield}	Kips	-5.703	6.155
	KN	-25.367	27.379
v_{yield}	Kips/ft.	-0.713	0.769
	KN/m	-10.403	11.228
Δ_{yield}	in.	-0.902	0.947
	mm	-22.90	24.05
$\Delta_{failure}$	in.	-3.979	3.421
	mm	-101.07	86.90

Ultimate parameters		units	negative	positive	average
SLS	F_{SLS}	Kips	-6.495	7.458	6.976
		KN	-28.889	33.176	31.032

Specimen 10b		For total length	
		CUREE cyclic test	
Effective wall length		96in.	2.44m

cycle	avg. displacement		avg. load		work per cycle		cumulative work		cyclic stiffness		damping	line
initial	in.	mm	Kips	KN	Kip·ft.	KN·m	Kip·ft.	KN·m	Kip/in.	KN/mm	ratio	number
	0	0	0	0	0	0	0	0				13
1	0.099	2.523	1.075	4.782	0.006	0.008	0.006	0.008	10.820	1.895	0.109	198
7	0.154	3.919	1.464	6.513	0.011	0.015	0.046	0.062	9.494	1.662	0.095	1402
14	0.206	5.231	1.778	7.907	0.018	0.025	0.105	0.142	8.635	1.512	0.096	2802
21	0.414	10.527	2.721	12.103	0.065	0.088	0.236	0.319	6.563	1.149	0.110	4202
25	0.625	15.867	3.429	15.253	0.116	0.158	0.451	0.611	5.488	0.961	0.104	5001
29	0.841	21.354	4.003	17.807	0.175	0.237	0.801	1.086	4.760	0.834	0.099	5801
32	1.491	37.860	5.373	23.897	0.519	0.704	1.494	2.025	3.603	0.631	0.124	6402
35	2.125	53.981	6.261	27.849	0.836	1.133	2.711	3.675	2.945	0.516	0.120	7002
38	2.873	72.967	6.976	31.031	1.653	2.241	4.978	6.748	2.443	0.428	0.156	7602
41	3.700	93.984	6.200	27.576	2.153	2.919	8.190	11.104	1.691	0.296	0.180	8203
44	0.299	7.601	0.723	3.214	0.034	0.046	22.060	29.908	2.102	0.368	0.248	8808

cycle	Negative stroke		Positive stroke		Negative stroke		Positive stroke		Area, Kip-in.		Unit load, KN/m	
initial	in.	Kips	in.	Kips	mm	KN	mm	KN	negative	positive	negative	positive
	0	0	0	0	0	0	0	0	0	0	0	0
1	-0.100	-1.088	0.099	1.062	-2.530	-4.838	2.517	4.725	0.054	0.053	-1.984	1.938
7	-0.156	-1.431	0.152	1.498	-3.970	-6.363	3.868	6.662	0.071	0.068	-2.610	2.732
14	-0.208	-1.718	0.204	1.838	-5.283	-7.640	5.179	8.173	0.081	0.086	-3.133	3.352
21	-0.411	-2.600	0.418	2.842	-10.442	-11.563	10.612	12.643	0.438	0.501	-4.742	5.185
25	-0.621	-3.293	0.629	3.565	-15.763	-14.649	15.972	15.856	0.617	0.676	-6.008	6.503
29	-0.823	-3.845	0.858	4.161	-20.904	-17.104	21.803	18.510	0.722	0.887	-7.014	7.591
32	-1.467	-5.177	1.514	5.568	-37.274	-23.028	38.445	24.767	2.907	3.187	-9.444	10.157
35	-2.106	-6.058	2.144	6.465	-53.495	-26.944	54.468	28.754	3.587	3.795	-11.050	11.792
38	-2.535	-6.495	3.211	7.458	-64.379	-28.888	81.554	33.174	2.689	7.424	-11.847	13.605
41	-3.979	-5.901	3.421	6.498	-101.072	-26.249	86.896	28.903	8.954	1.467	-10.765	11.853

Specimen 11a	For total length		Specimen 11a	Per unit length	
	CUREE cyclic test			CUREE cyclic test	
Effective wall length	96in.	2.44m	Effective wall length	96in.	2.44m
Date:	Time:		Date:	Time:	
EEEP Parameters	units	initial	EEEP Parameters	units	initial
Peak load, F_{peak}	Kips	6.480	Peak unit load, v_{peak}	Kip/ft.	0.810
	KN	28.821		KN/m	11.820
Drift at peak load, Δ_{peak}	in.	3.768	Drift at capacity, Δ_{peak}	in.	3.768
	mm	95.71		mm	95.71
Yield load, F_{yield}	Kips	5.540	Yield unit load, v_{yield}	Kip/ft.	0.692
	KN	24.640		KN/m	10.105
Drift at yield load, Δ_{yield}	in.	1.386	Drift at yield load, Δ_{yield}	in.	1.386
	mm	35.21		mm	35.21
Proportional limit, $0.4F_{peak}$	Kips	2.592	Proportional limit, $0.4v_{peak}$	Kip/ft.	0.324
	KN	11.528		KN/m	4.728
Drift at prop. limit, $\Delta @ 0.4F_{peak}$	in.	0.649	Drift at prop. limit, $\Delta @ 0.4v_{peak}$	in.	0.649
	mm	16.49		mm	16.49
Failure load or $0.8F_{peak}$	Kips	6.480	Unit load at failure or $0.8v_{peak}$	Kip/ft.	0.810
	KN	28.821		KN/m	11.820
Drift at failure, $\Delta_{failure}$	in.	3.768	Drift at failure, $\Delta_{failure}$	in.	3.768
	mm	95.71		mm	95.71
Elastic stiffness, K_e @$0.4F_{peak}$	Kip/in.	4.010	Shear modulus, G @$0.4F_{peak}$	Kip/in	4.010
	KN/mm	0.702		KN/mm	0.702
Work until failure	Kip·ft.	6.335	Work until failure per unit length	Kip·ft./ft.	0.792
	KN·m	8.588		KN·m/m	3.522
Load @ .32 in. (8.13 mm)	Kips	1.514	Unit load @ .32 in. (8.13 mm)	Kips/ft.	0.189
	KN	6.736		KN/m	2.763
Load @ .48 in. (12.19 mm)	Kips	2.068	Unit load @ .48 in. (12.19 mm)	Kips/ft.	0.258
	KN	9.197		KN/m	3.772
Load @ .96 in. (24.38 mm)	Kips	3.396	Unit load @ .96 in. (24.38 mm)	Kips/ft.	0.424
	KN	15.104		KN/m	6.194
Load @ 1.6 in. (40.64 mm)	Kips	4.680	Unit load @ 1.6 in. (40.64 mm)	Kips/ft.	0.585
	KN	20.815		KN/m	8.536
Ductility factor, μ		2.72	$\zeta_{eq} @ v_{peak}$		0.136

		initial	
EEEP Parameters	units	negative	positive
F_{yield}	Kips	-5.576	5.503
	KN	-24.801	24.479
v_{yield}	Kips/ft.	-0.697	0.688
	KN/m	-10.171	10.039
Δ_{yield}	in.	-1.473	1.299
	mm	-37.41	33.00
$\Delta_{failure}$	in.	-3.979	3.557
	mm	-101.06	90.35

Ultimate parameters		units	negative	positive	average
SLS	F_{SLS}	Kips	-6.635	6.324	6.480
		KN	-29.516	28.129	28.822

Specimen 11a	For total length	
	CUREE cyclic test	
Effective wall length	96in.	2.44m

cycle	avg. displacement		avg. load		work per cycle		cumulative work		cyclic stiffness		damping ratio	line number
initial	in.	mm	Kips	KN	Kip·ft.	KN·m	Kip·ft.	KN·m	Kip/in.	KN/mm		
	0	0	0	0	0	0	0	0				13
1	0.099	2.516	0.660	2.934	0.004	0.005	0.004	0.005	6.690	1.171	0.117	111
7	0.153	3.891	0.887	3.944	0.007	0.010	0.030	0.040	5.794	1.015	0.102	780
14	0.206	5.222	1.103	4.906	0.011	0.015	0.066	0.089	5.366	0.940	0.093	1557
21	0.419	10.645	1.871	8.322	0.038	0.052	0.144	0.195	4.464	0.782	0.094	2335
25	0.633	16.068	2.562	11.397	0.077	0.104	0.279	0.379	4.049	0.709	0.091	2779
29	0.846	21.500	3.151	14.015	0.123	0.167	0.516	0.699	3.720	0.651	0.088	3223
32	1.469	37.313	4.498	20.006	0.398	0.540	1.036	1.405	3.060	0.536	0.115	3557
35	2.044	51.923	5.295	23.553	0.680	0.922	2.007	2.721	2.591	0.454	0.120	3890
38	3.118	79.191	6.210	27.622	1.324	1.795	3.802	5.154	1.992	0.349	0.131	4224
41	3.768	95.706	6.480	28.821	1.735	2.352	6.335	8.588	1.723	0.302	0.136	4558
44	0.299	7.601	0.723	3.214	0.034	0.046	22.060	29.908	2.102	0.368	0.248	8808

cycle	Negative stroke		Positive stroke		Negative stroke		Positive stroke		Area, Kip-in.		Unit load, KN/m	
initial	in.	Kips	in.	Kips	mm	KN	mm	KN	negative	positive	negative	positive
	0	0	0	0	0	0	0	0	0	0	0	0
1	-0.105	-0.650	0.093	0.670	-2.670	-2.889	2.362	2.978	0.034	0.031	-1.185	1.221
7	-0.156	-0.858	0.150	0.915	-3.962	-3.818	3.820	4.071	0.038	0.045	-1.566	1.669
14	-0.207	-1.067	0.204	1.138	-5.258	-4.748	5.187	5.064	0.049	0.055	-1.947	2.077
21	-0.418	-1.804	0.420	1.938	-10.617	-8.025	10.673	8.618	0.303	0.332	-3.291	3.534
25	-0.623	-2.445	0.642	2.679	-15.829	-10.877	16.307	11.917	0.436	0.512	-4.461	4.887
29	-0.829	-2.997	0.864	3.304	-21.062	-13.332	21.938	14.698	0.561	0.663	-5.467	6.028
32	-1.445	-4.302	1.493	4.694	-36.700	-19.135	37.925	20.877	2.247	2.517	-7.847	8.562
35	-2.062	-5.165	2.026	5.426	-52.377	-22.973	51.468	24.134	2.921	2.698	-9.421	9.897
38	-3.069	-6.125	3.167	6.295	-77.950	-27.244	80.432	28.000	5.683	6.683	-11.173	11.483
41	-3.979	-6.635	3.557	6.324	-101.064	-29.514	90.348	28.128	5.806	2.463	-12.104	11.535

Specimen 11b	For total length	
	CUREE cyclic test	
Effective wall length	96in.	2.44m
Date:	Time:	
EEEP Parameters	units	initial
Peak load, F_{peak}	Kips	5.669
	KN	25.213
Drift at peak load, Δ_{peak}	in.	3.162
	mm	80.32
Yield load, F_{yield}	Kips	4.897
	KN	21.781
Drift at yield load, Δ_{yield}	in.	0.997
	mm	25.32
Proportional limit, $0.4F_{peak}$	Kips	2.267
	KN	10.085
Drift at prop. limit, $\Delta@0.4F_{peak}$	in.	0.461
	mm	11.71
Failure load or $0.8F_{peak}$	Kips	4.999
	KN	22.234
Drift at failure, $\Delta_{failure}$	in.	4.152
	mm	105.45
Elastic stiffness, K_e @$0.4F_{peak}$	Kip/in.	4.946
	KN/mm	0.866
Work until failure	Kip·ft.	6.195
	KN·m	8.398
Load @ .32 in. (8.13 mm)	Kips	1.816
	KN	8.080
Load @ .48 in. (12.19 mm)	Kips	2.323
	KN	10.334
Load @ .96 in. (24.38 mm)	Kips	3.391
	KN	15.084
Load @ 1.6 in. (40.64 mm)	Kips	4.418
	KN	19.651
Ductility factor, μ		4.22

Specimen 11b	Per unit length	
	CUREE cyclic test	
Effective wall length	96in.	2.44m
Date:	Time:	
EEEP Parameters	units	initial
Peak unit load, v_{peak}	Kip/ft.	0.709
	KN/m	10.340
Drift at capacity, Δ_{peak}	in.	3.162
	mm	80.32
Yield unit load, v_{yield}	Kip/ft.	0.612
	KN/m	8.932
Drift at yield load, Δ_{yield}	in.	0.997
	mm	25.32
Proportional limit, $0.4v_{peak}$	Kip/ft.	0.283
	KN/m	4.136
Drift at prop. limit, $\Delta@0.4v_{peak}$	in.	0.461
	mm	11.71
Unit load at failure or $0.8v_{peak}$	Kip/ft.	0.625
	KN/m	9.118
Drift at failure, $\Delta_{failure}$	in.	4.152
	mm	105.45
Shear modulus, G @$0.4F_{peak}$	Kip/in.	4.946
	KN/mm	0.866
Work until failure per unit length	Kip·ft./ft.	0.774
	KN·m/m	3.444
Unit load @ .32 in. (8.13 mm)	Kips/ft.	0.227
	KN/m	3.313
Unit load @ .48 in. (12.19 mm)	Kips/ft.	0.290
	KN/m	4.238
Unit load @ .96 in. (24.38 mm)	Kips/ft.	0.424
	KN/m	6.186
Unit load @ 1.6 in. (40.64 mm)	Kips/ft.	0.552
	KN/m	8.059
ζ_{eq} @v_{peak}		0.139

		initial	
EEEP Parameters	units	negative	positive
F_{yield}	Kips	-4.636	5.158
	KN	-20.619	22.943
v_{yield}	Kips/ft.	-0.579	0.645
	KN/m	-8.456	9.409
Δ_{yield}	in.	-0.885	1.109
	mm	-22.47	28.16
$\Delta_{failure}$	in.	-4.162	4.141
	mm	-105.71	105.19

Ultimate parameters		units	negative	positive	average
SLS	F_{SLS}	Kips	-5.438	5.899	5.669
		KN	-24.190	26.240	25.215

Specimen 11b	For total length	
	CUREE cyclic test	
Effective wall length	96in.	2.44m

cycle	avg. displacement		avg. load		work per cycle		cumulative work		cyclic stiffness		damping ratio	line number
initial	in.	mm	Kips	KN	Kip·ft.	KN·m	Kip·ft.	KN·m	Kip/in.	KN/mm		
	0	0	0	0	0	0	0	0				13
1	0.100	2.543	0.856	3.810	0.004	0.006	0.004	0.006	8.570	1.501	0.095	198
7	0.155	3.947	1.173	5.218	0.008	0.011	0.033	0.045	7.551	1.322	0.086	1401
14	0.206	5.240	1.417	6.303	0.013	0.018	0.076	0.104	6.870	1.203	0.087	2801
21	0.418	10.618	2.161	9.613	0.046	0.063	0.170	0.230	5.170	0.905	0.098	4200
25	0.634	16.096	2.725	12.121	0.086	0.117	0.326	0.442	4.301	0.753	0.095	5000
29	0.842	21.391	3.192	14.196	0.132	0.179	0.585	0.793	3.790	0.664	0.094	5800
32	1.502	38.142	4.314	19.190	0.404	0.548	1.117	1.514	2.873	0.503	0.119	6400
35	2.148	54.555	5.023	22.340	0.663	0.899	2.061	2.794	2.338	0.409	0.117	7000
38	3.162	80.321	5.669	25.213	1.304	1.767	3.822	5.182	1.793	0.314	0.139	7600
41	3.630	92.197	5.100	22.684	1.646	2.232	6.195	8.398	1.412	0.247	0.167	8201
44	0.299	7.601	0.723	3.214	0.034	0.046	22.060	29.908	2.102	0.368	0.248	8808

cycle	Negative stroke		Positive stroke		Negative stroke		Positive stroke		Area, Kip-in.		Unit load, KN/m	
initial	in.	Kips	in.	Kips	mm	KN	mm	KN	negative	positive	negative	positive
	0	0	0	0	0	0	0	0	0	0	0	0
1	-0.107	-0.896	0.093	0.817	-2.718	-3.984	2.367	3.636	0.048	0.038	-1.634	1.491
7	-0.159	-1.184	0.152	1.162	-4.031	-5.268	3.863	5.168	0.054	0.058	-2.160	2.119
14	-0.210	-1.430	0.203	1.404	-5.324	-6.360	5.156	6.246	0.067	0.065	-2.608	2.562
21	-0.419	-2.188	0.418	2.135	-10.630	-9.730	10.607	9.496	0.378	0.380	-3.990	3.894
25	-0.626	-2.754	0.641	2.696	-15.898	-12.249	16.294	11.993	0.512	0.541	-5.023	4.918
29	-0.835	-3.200	0.850	3.183	-21.201	-14.235	21.580	14.157	0.622	0.612	-5.838	5.806
32	-1.473	-4.229	1.531	4.400	-37.407	-18.811	38.877	19.570	2.370	2.582	-7.714	8.026
35	-2.111	-4.838	2.185	5.207	-53.609	-21.521	55.502	23.159	2.892	3.144	-8.826	9.498
38	-3.179	-5.438	3.145	5.899	-80.752	-24.189	79.891	26.238	5.491	5.332	-9.920	10.760
41	-4.247	-4.256	4.141	5.647	-107.874	-18.932	105.192	25.117	5.176	5.750	-7.764	10.301

Specimen 12a	For total length	
	CUREE cyclic test	
Effective wall length	96in.	2.44m
Date:	Time:	
EEEP Parameters	units	initial
Peak load, F_{peak}	Kips	16.034
	KN	71.320
Drift at peak load, Δ_{peak}	in.	3.377
	mm	85.78
Yield load, F_{yield}	Kips	14.141
	KN	62.900
Drift at yield load, Δ_{yield}	in.	0.936
	mm	23.77
Proportional limit, $0.4F_{peak}$	Kips	6.414
	KN	28.528
Drift at prop. limit, $\Delta@0.4F_{peak}$	in.	0.425
	mm	10.78
Failure load or $0.8F_{peak}$	Kips	12.827
	KN	57.056
Drift at failure, $\Delta_{failure}$	in.	3.210
	mm	81.52
Elastic stiffness, K_e @$0.4F_{peak}$	Kip/in.	15.113
	KN/mm	2.647
Work until failure	Kip·ft.	22.060
	KN·m	29.908
Load @ .32 in. (8.13 mm)	Kips	5.406
	KN	24.044
Load @ .48 in. (12.19 mm)	Kips	6.816
	KN	30.317
Load @ .96 in. (24.38 mm)	Kips	9.999
	KN	44.476
Load @ 1.6 in. (40.64 mm)	Kips	13.261
	KN	58.983
Ductility factor, μ		3.46

Specimen 12a	Per unit length	
	CUREE cyclic test	
Effective wall length	96in.	2.44m
Date:	Time:	
EEEP Parameters	units	initial
Peak unit load, v_{peak}	Kip/ft.	2.004
	KN/m	29.249
Drift at capacity, Δ_{peak}	in.	3.377
	mm	85.78
Yield unit load, v_{yield}	Kip/ft.	1.768
	KN/m	25.796
Drift at yield load, Δ_{yield}	in.	0.936
	mm	23.77
Proportional limit, $0.4v_{peak}$	Kip/ft.	0.802
	KN/m	11.699
Drift at prop. limit, $\Delta@0.4v_{peak}$	in.	0.425
	mm	10.78
Unit load at failure or $0.8v_{peak}$	Kip/ft.	1.603
	KN/m	23.399
Drift at failure, $\Delta_{failure}$	in.	3.210
	mm	81.52
Shear modulus, G @$0.4F_{peak}$	Kip/in.	15.113
	KN/mm	2.647
Work until failure per unit length	Kip·ft./ft.	2.758
	KN·m/m	12.265
Unit load @ .32 in. (8.13 mm)	Kips/ft.	0.676
	KN/m	9.861
Unit load @ .48 in. (12.19 mm)	Kips/ft.	0.852
	KN/m	12.433
Unit load @ .96 in. (24.38 mm)	Kips/ft.	1.250
	KN/m	18.240
Unit load @ 1.6 in. (40.64 mm)	Kips/ft.	1.658
	KN/m	24.189
ζ_{eq} @v_{peak}		0.151

	initial	
EEEP Parameters	units	negative	positive
F_{yield}	Kips	-14.883	13.400
	KN	-66.197	59.602
v_{yield}	Kips/ft.	-1.860	1.675
	KN/m	-27.148	24.443
Δ_{yield}	in.	-0.989	0.883
	mm	-25.12	22.42
$\Delta_{failure}$	in.	-3.642	4.160
	mm	-92.50	105.66

Ultimate parameters		units	negative	positive	average
SLS	F_{SLS}	Kips	-17.083	14.985	16.034
		KN	-75.990	66.657	71.324

Specimen 12a		For total length												
		CUREE cyclic test												
Effective wall length		96in.	2.44m											
cycle	avg. displacement		avg. load		work per cycle		cumulative work		cyclic stiffness		damping	line
initial	in.	mm	Kips	KN	Kip·ft.	KN·m	Kip·ft.	KN·m	Kip/in.	KN/mm	ratio	number
	0	0	0	0	0	0	0	0				13
1	0.057	1.449	1.778	7.907	0.006	0.008	0.006	0.008	31.250	5.472	0.109	198
7	0.137	3.482	3.234	14.384	0.026	0.035	0.087	0.118	23.588	4.131	0.112	1402
14	0.186	4.721	3.922	17.445	0.041	0.056	0.218	0.296	21.105	3.696	0.109	2801
21	0.371	9.434	5.963	26.522	0.140	0.190	0.508	0.689	16.082	2.816	0.121	4199
25	0.577	14.656	7.532	33.503	0.273	0.370	1.014	1.375	13.113	2.296	0.120	4999
29	0.767	19.477	8.844	39.338	0.411	0.558	1.844	2.500	11.590	2.030	0.116	5799
32	1.354	34.387	12.261	54.538	1.187	1.609	3.459	4.689	9.100	1.594	0.137	6400
35	1.951	49.544	14.418	64.130	2.019	2.737	6.424	8.709	7.460	1.306	0.137	6999
38	2.941	74.698	15.831	70.415	3.841	5.207	11.776	15.965	5.418	0.949	0.158	7600
41	3.901	99.078	15.734	69.986	4.621	6.264	18.833	25.533	4.075	0.714	0.145	8201
44	0.299	7.601	0.723	3.214	0.034	0.046	22.060	29.908	2.102	0.368	0.248	8808

cycle	Negative stroke		Positive stroke		Negative stroke		Positive stroke		Area, Kip-in.		Unit load, KN/m	
initial	in.	Kips	in.	Kips	mm	KN	mm	KN	negative	positive	negative	positive
	0	0	0	0	0	0	0	0	0	0	0	0
1	-0.062	-1.872	0.052	1.683	-1.575	-8.327	1.323	7.486	0.058	0.044	-3.415	3.070
7	-0.137	-3.271	0.138	3.197	-3.472	-14.549	3.493	14.219	0.192	0.208	-5.967	5.831
14	-0.185	-3.958	0.187	3.886	-4.691	-17.607	4.750	17.284	0.174	0.175	-7.221	7.088
21	-0.357	-5.993	0.386	5.932	-9.068	-26.659	9.799	26.386	0.857	0.976	-10.933	10.821
25	-0.540	-7.576	0.614	7.489	-13.716	-33.697	15.596	33.310	1.242	1.531	-13.819	13.661
29	-0.717	-8.931	0.816	8.757	-18.217	-39.727	20.737	38.950	1.463	1.644	-16.292	15.974
32	-1.270	-12.440	1.438	12.082	-32.253	-55.335	36.520	53.742	5.905	6.475	-22.693	22.040
35	-1.794	-14.898	2.107	13.937	-45.560	-66.267	53.528	61.993	7.161	8.711	-27.176	25.423
38	-2.769	-16.677	3.113	14.985	-70.330	-74.177	79.065	66.654	15.396	14.539	-30.420	27.335
41	-3.642	-17.083	4.160	14.385	-92.497	-75.986	105.659	63.986	14.731	15.375	-31.162	26.241
44	-0.212	-0.218	0.387	1.227	-5.385	-0.970	9.817	5.457	-29.668	-29.455	-0.398	2.238

Specimen 12b	For total length		Specimen 12b	Per unit length	
	CUREE cyclic test			CUREE cyclic test	
Effective wall length	96in.	2.44m	Effective wall length	96in.	2.44m
Date:	Time:		Date:	Time:	
EEEP Parameters	units	initial	EEEP Parameters	units	initial
Peak load, F_{peak}	Kips	15.009	Peak unit load, v_{peak}	Kip/ft.	1.876
	KN	66.758		KN/m	27.378
Drift at peak load, Δ_{peak}	in.	3.422	Drift at capacity, Δ_{peak}	in.	3.422
	mm	86.91		mm	86.91
Yield load, F_{yield}	Kips	13.035	Yield unit load, v_{yield}	Kip/ft.	1.629
	KN	57.980		KN/m	23.778
Drift at yield load, Δ_{yield}	in.	0.813	Drift at yield load, Δ_{yield}	in.	0.813
	mm	20.65		mm	20.65
Proportional limit, $0.4F_{peak}$	Kips	6.003	Proportional limit, $0.4v_{peak}$	Kip/ft.	0.750
	KN	26.703		KN/m	10.951
Drift at prop. limit, $\Delta@0.4F_{peak}$	in.	0.374	Drift at prop. limit, $\Delta@0.4v_{peak}$	in.	0.374
	mm	9.51		mm	9.51
Failure load or $0.8F_{peak}$	Kips	15.009	Unit load at failure or $0.8v_{peak}$	Kip/ft.	1.876
	KN	66.758		KN/m	27.378
Drift at failure, $\Delta_{failure}$	in.	3.422	Drift at failure, $\Delta_{failure}$	in.	3.422
	mm	86.91		mm	86.91
Elastic stiffness, K_e @$0.4F_{peak}$	Kip/in.	16.038	Shear modulus, G @$0.4F_{peak}$	Kip/in.	16.038
	KN/mm	2.809		KN/mm	2.809
Work until failure	Kip·ft.	17.195	Work until failure per unit length	Kip·ft./ft.	2.149
	KN·m	23.312		KN·m/m	9.560
Load @ .32 in. (8.13 mm)	Kips	5.400	Unit load @ .32 in. (8.13 mm)	Kips/ft.	0.675
	KN	24.019		KN/m	9.850
Load @ .48 in. (12.19 mm)	Kips	6.871	Unit load @ .48 in. (12.19 mm)	Kips/ft.	0.859
	KN	30.561		KN/m	12.533
Load @ .96 in. (24.38 mm)	Kips	9.945	Unit load @ .96 in. (24.38 mm)	Kips/ft.	1.243
	KN	44.236		KN/m	18.142
Load @ 1.6 in. (40.64 mm)	Kips	13.004	Unit load @ 1.6 in. (40.64 mm)	Kips/ft.	1.625
	KN	57.841		KN/m	23.721
Ductility factor, μ		4.19	ζ_{eq} @v_{peak}		0.161

		initial	
EEEP Parameters	units	negative	positive
F_{yield}	Kips	-12.613	13.457
	KN	-56.103	59.858
v_{yield}	Kips/ft.	-1.577	1.682
	KN/m	-23.008	24.548
Δ_{yield}	in.	-0.781	0.845
	mm	-19.84	21.46
$\Delta_{failure}$	in.	-2.827	4.017
	mm	-71.80	102.02

Ultimate parameters		units	negative	positive	average
SLS	F_{SLS}	Kips	-14.884	15.133	15.009
		KN	-66.208	67.315	66.762

Specimen 12b	For total length	
	CUREE cyclic test	
Effective wall length	96in.	2.44m

cycle	avg. displacement		avg. load		work per cycle		cumulative work		cyclic stiffness		damping ratio	line number
initial	in.	mm	Kips	KN	Kip·ft.	KN·m	Kip·ft.	KN·m	Kip/in.	KN/mm		
	0	0	0	0	0	0	0	0				13
1	0.090	2.287	2.376	10.571	0.014	0.019	0.014	0.019	26.408	4.625	0.125	195
7	0.143	3.627	3.239	14.405	0.026	0.035	0.102	0.139	22.687	3.973	0.106	1399
14	0.191	4.858	3.967	17.647	0.042	0.057	0.238	0.323	20.750	3.634	0.106	2799
21	0.385	9.780	6.121	27.228	0.147	0.199	0.538	0.729	15.902	2.785	0.119	4199
25	0.588	14.938	7.712	34.305	0.277	0.376	1.047	1.420	13.126	2.299	0.117	4999
29	0.790	20.060	8.998	40.023	0.429	0.582	1.892	2.564	11.411	1.998	0.115	5799
32	1.378	35.006	12.209	54.304	1.225	1.661	3.543	4.803	8.886	1.556	0.139	6399
35	1.930	49.023	14.214	63.225	2.106	2.855	6.612	8.964	7.373	1.291	0.147	6999
38	2.562	65.082	13.859	61.647	2.842	3.853	10.971	14.874	5.633	0.986	0.151	7589
41	3.422	86.911	15.009	66.758	4.330	5.871	17.195	23.312	4.517	0.791	0.161	8203

cycle	Negative stroke		Positive stroke		Negative stroke		Positive stroke		Area, Kip-in.		Unit load, KN/m	
initial	in.	Kips	in.	Kips	mm	KN	mm	KN	negative	positive	negative	positive
	0	0	0	0	0	0	0	0	0	0	0	0
1	-0.092	-2.343	0.088	2.410	-2.332	-10.421	2.243	10.720	0.108	0.106	-4.274	4.396
7	-0.138	-3.153	0.148	3.324	-3.498	-14.025	3.757	14.785	0.126	0.171	-5.752	6.063
14	-0.186	-3.887	0.197	4.048	-4.719	-17.289	4.996	18.006	0.169	0.180	-7.090	7.384
21	-0.375	-6.027	0.395	6.216	-9.533	-26.810	10.028	27.647	0.939	1.017	-10.995	11.338
25	-0.565	-7.578	0.612	7.847	-14.343	-33.705	15.532	34.905	1.288	1.524	-13.823	14.315
29	-0.754	-8.893	0.825	9.102	-19.157	-39.558	20.963	40.488	1.561	1.812	-16.223	16.604
32	-1.292	-12.039	1.465	12.379	-32.809	-53.548	37.203	55.060	5.626	6.867	-21.960	22.580
35	-1.846	-13.985	2.014	14.444	-46.899	-62.204	51.148	64.247	7.218	7.363	-25.510	26.348
38	-1.988	-13.179	3.137	14.540	-50.490	-58.621	79.675	64.673	1.920	16.276	-24.041	26.523
41	-2.827	-14.884	4.017	15.133	-71.798	-66.205	102.024	67.312	11.771	13.055	-27.151	27.605

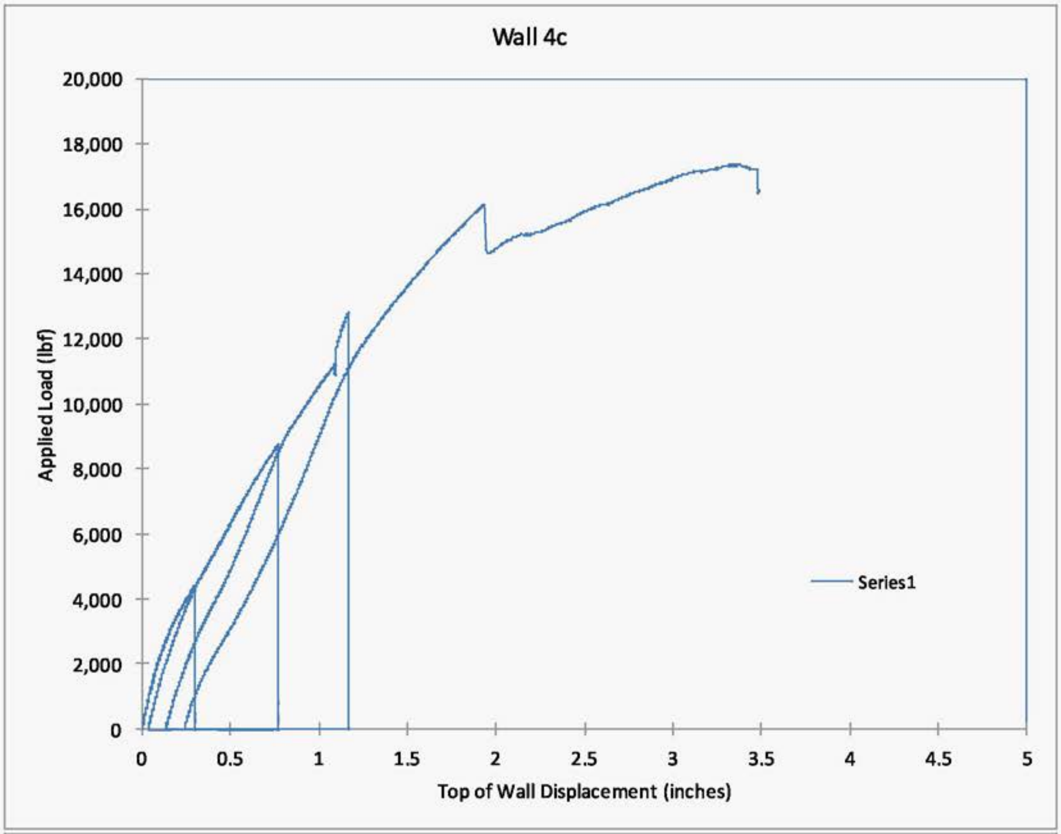
yclic test data analyzed following FEMA P-795 (Sept 2010 version) methodology.

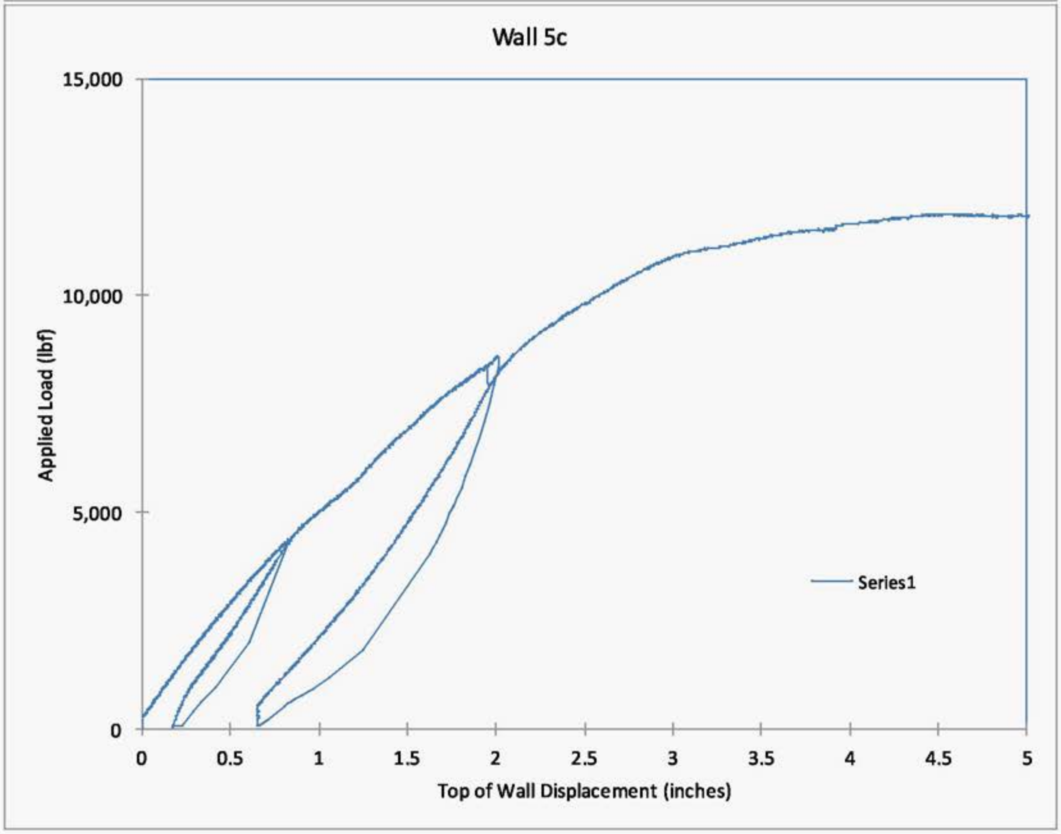
	Strength						Stiffness								Strength/Stiffness				Deformation Capacity				Ductility factor, μ	
Wall Number	V_{M-} (lbf)	V_{M+} (lbf)	V_M (lbf)	V_D (lbf)	R_Q	Median R_Q	K_{I-} (lbf/in.)	K_{I+} (lbf/in.)	K_I (lbf/in.)	K_{D-} (lbf/in.)	K_{D+} (lbf/in.)	K_D (1) (lbf/in.)	R_K	Median R_K	Δ_{I-} (in./in.)	Δ_{I+} (in./in.)	Δ_I (in./in.)	Median Δ_I	Δ_{U-} (in./in.)	Δ_{U+} (in./in.)	Δ_U (in./in.)	Median Δ_U	μ	Median μ
1a	-5,366	5,475	5,421	3,915	1.38	1.44	2,619	2,591	2,605	2,426	2,189	2,308	1.13	1.07	-0.009	0.009	0.009	0.010	-0.041	0.042	0.041	0.042	4.77	4.35
1b	-5,767	5,908	5,837	3,915	1.49		2,195	2,307	2,251	1,900	2,593	2,246	1.00		-0.011	0.011	0.011		-0.042	0.042	0.042		3.92	
2a	-7,479	7,112	7,296	3,631	2.01	1.96	8,825	7,395	8,110	8,561	6,349	7,455	1.09	1.07	-0.004	0.004	0.004	0.003	-0.030	0.021	0.026	0.026	6.79	7.67
2b	-6,316	7,534	6,925	3,631	1.91		9,865	9,316	9,591	9,223	9,146	9,184	1.04		-0.003	0.003	0.003		-0.028	0.024	0.026		8.56	
3a	-9,712	11,028	10,370	3,631	2.86	2.66	11,085	10,563	10,824	11,214	11,623	11,418	0.95	0.98	-0.004	0.004	0.004	0.004	-0.032	0.037	0.035	0.030	8.66	7.87
3b	-8,367	9,543	8,955	3,631	2.47		10,817	10,740	10,779	10,409	10,920	10,664	1.01		-0.003	0.004	0.003		-0.019	0.030	0.025		7.08	
4a	-14,085	15,779	14,932	3,915	3.81		11,101	13,968	12,535	11,450	16,185	13,817	0.91		-0.005	0.005	0.005		-0.018	0.026	0.022		4.40	
4b	-16,415	18,059	17,237	3,915	4.40	3.92	13,142	14,468	13,805	13,826	17,461	15,644	0.88	0.88	-0.005	0.005	0.005	0.005	-0.033	0.035	0.034	0.034	6.58	6.58
4d	-15,822	14,834	15,328	3,915	3.92		11,678	13,039	12,359	14,124	15,913	15,018	0.82		-0.006	0.005	0.005		-0.035	0.039	0.037		7.14	
5b	-13,404	13,568	13,486	3,915	3.44	3.21	7,793	6,868	7,331	8,485	7,511	7,998	0.92	0.93	-0.007	0.008	0.008	0.007	-0.036	0.043	0.040	0.038	5.13	5.68
5d	-10,832	12,531	11,682	3,915	2.98		8,095	8,531	8,313	8,421	9,222	8,821	0.94		-0.006	0.006	0.006		-0.034	0.039	0.036		6.22	
6a	-10,596	13,301	11,948	3,915	3.05	3.26	18,090	21,778	19,934	18,526	25,604	22,065	0.90	1.26	-0.002	0.003	0.002	0.002	-0.039	0.037	0.038	0.038	15.21	15.54
6b	-13,026	14,138	13,582	3,915	3.47		23,999	23,800	23,900	3,252	26,446	14,849	1.61		-0.002	0.002	0.002		-0.034	0.041	0.038		15.87	
7a	-12,295	12,778	12,536	6,960	1.80	1.68	16,539	17,575	17,057	14,183	14,871	14,527	1.17	1.26	-0.003	0.003	0.003	0.003	-0.031	0.031	0.031	0.031	10.18	11.66
7b	-10,452	11,333	10,893	6,960	1.57		18,139	19,609	18,874	13,466	14,591	14,029	1.35		-0.002	0.002	0.002		-0.037	0.026	0.032		13.14	
8a	-14,910	15,868	15,389	6,960	2.21	2.22	23,880	18,316	21,098	21,782	17,549	19,665	1.07	1.07	-0.003	0.004	0.003	0.003	-0.030	0.038	0.034	0.034	10.88	11.01
8b	-14,579	16,461	15,520	6,960	2.23		21,390	19,869	20,630	19,133	19,177	19,155	1.08		-0.003	0.003	0.003		-0.029	0.042	0.035		11.15	
9a	-15,291	15,213	15,252	6,960	2.19	2.29	18,477	16,323	17,400	17,456	14,999	16,228	1.07	1.05	-0.003	0.004	0.004	0.004	-0.026	0.031	0.028	0.032	7.77	7.97
9b	-16,611	16,684	16,647	6,960	2.39		15,478	15,677	15,577	15,193	15,360	15,277	1.02		-0.004	0.004	0.004		-0.037	0.035	0.036		8.18	
10a	-7,006	7,941	7,473	3,480	2.15	2.08	4,774	4,781	4,777	4,239	4,569	4,404	1.08	1.14	-0.006	0.007	0.007	0.006	-0.034	0.043	0.039	0.039	5.91	7.21
10b	-6,495	7,458	6,976	3,480	2.00		6,326	6,500	6,413	5,051	5,761	5,406	1.19		-0.004	0.005	0.005		-0.041	0.036	0.039		8.51	
11a	-6,635	6,324	6,480	3,480	1.86	1.75	3,786	4,235	4,010	3,292	3,689	3,491	1.15	1.29	-0.007	0.006	0.007	0.006	-0.041	0.037	0.039	0.041	5.80	7.40
11b	-5,438	5,899	5,669	3,480	1.63		5,240	4,652	4,946	3,452	3,425	3,439	1.44		-0.004	0.005	0.005		-0.043	0.043	0.043		9.00	
12a	-17,083	14,985	16,034	5,220	3.07	2.97	16,047	16,179	15,113	17,906	16,486	17,196	0.88	0.91	-0.005	0.004	0.004	0.004	-0.038	0.043	0.041	0.038	9.19	9.16
12b	-14,884	15,133	15,009	5,220	2.88		16,144	15,931	16,038	17,181	17,182	17,181	0.93		-0.004	0.004	0.004		-0.029	0.042	0.036		9.14	

1) FEMA P-795 bases K_D on calculated deflection, for above table, deflection was based on observed drift at V_D.

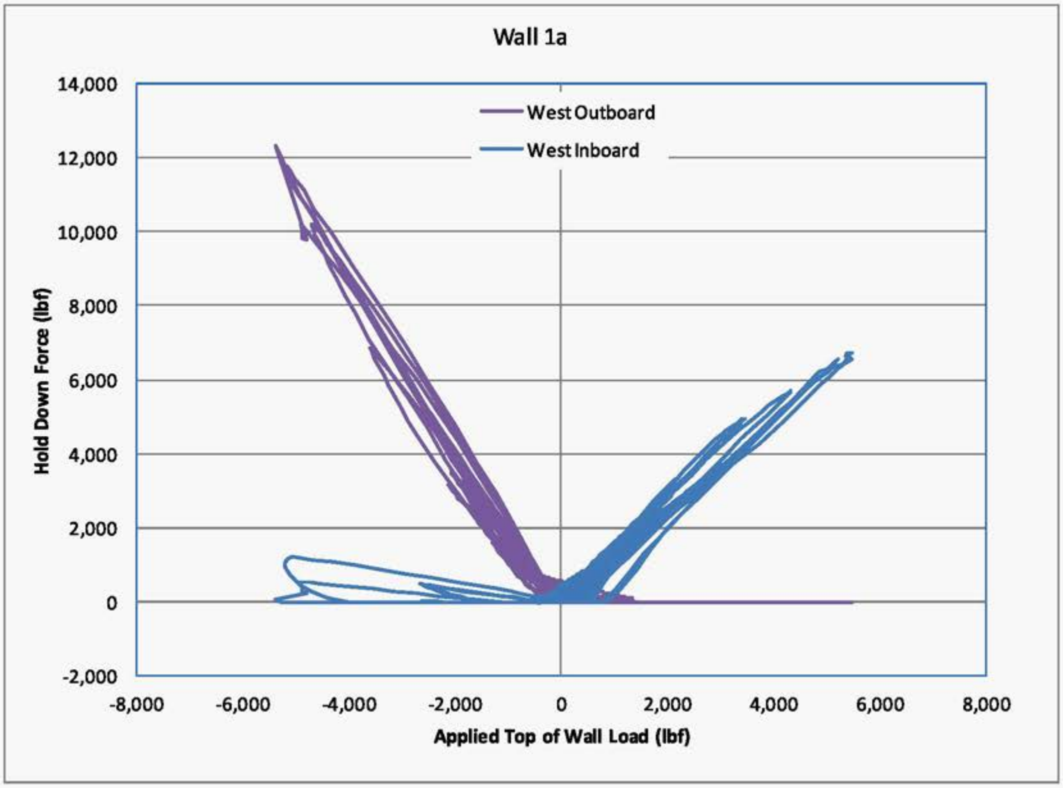
2) Δ_U/Δ_I

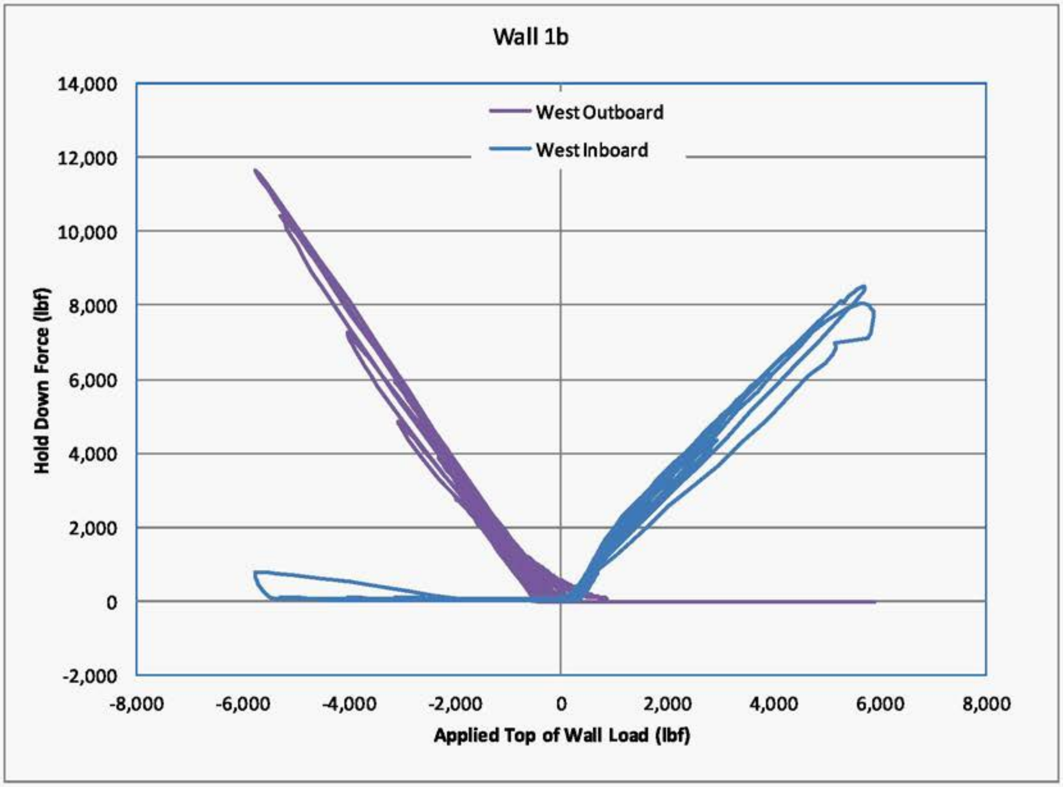
APPENDIX B – MONOTONIC TESTS, GLOBAL WALL DATA

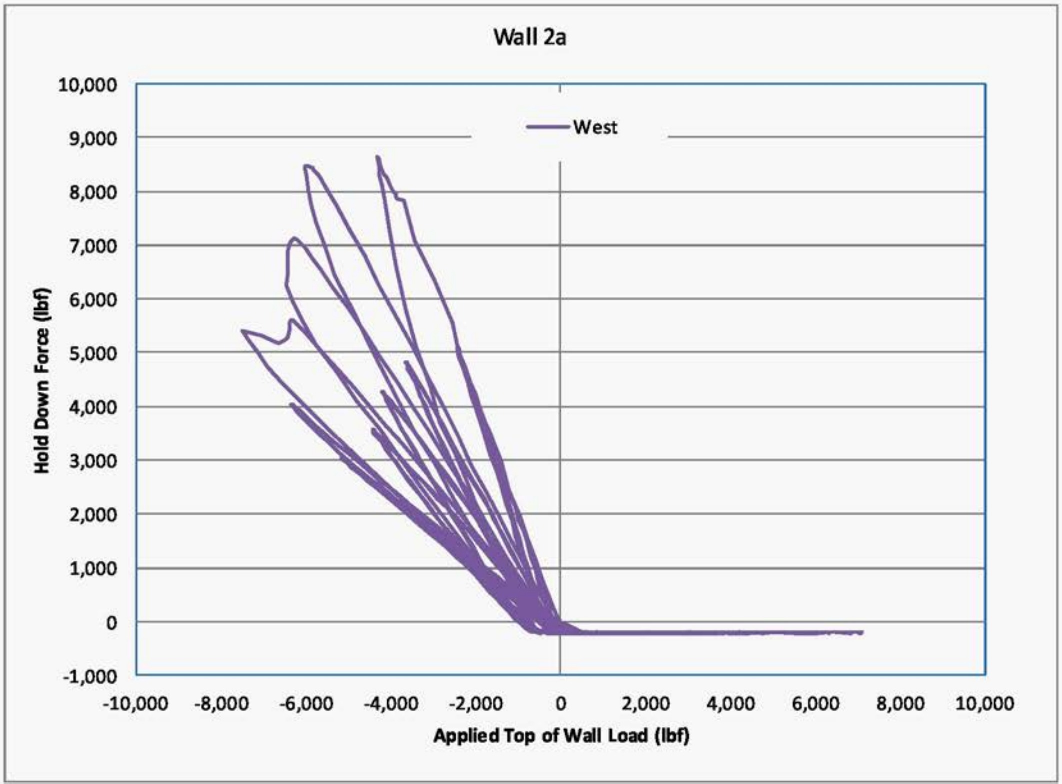


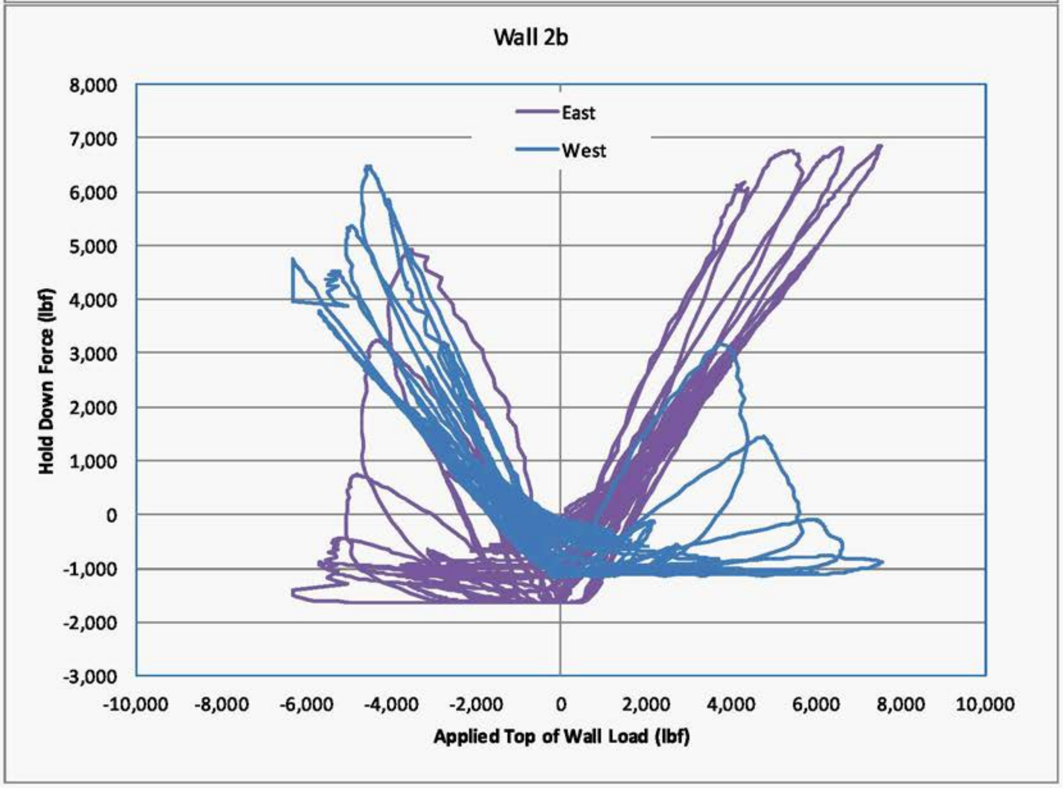


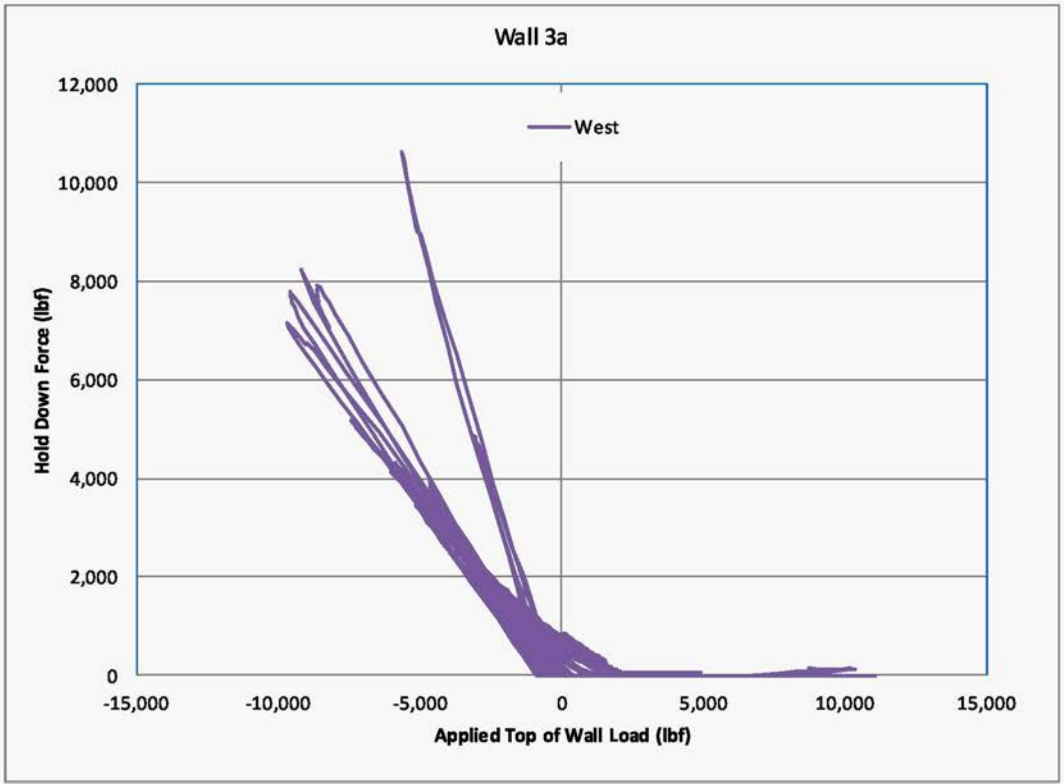
APPENDIX C – HOLD-DOWN FORCES

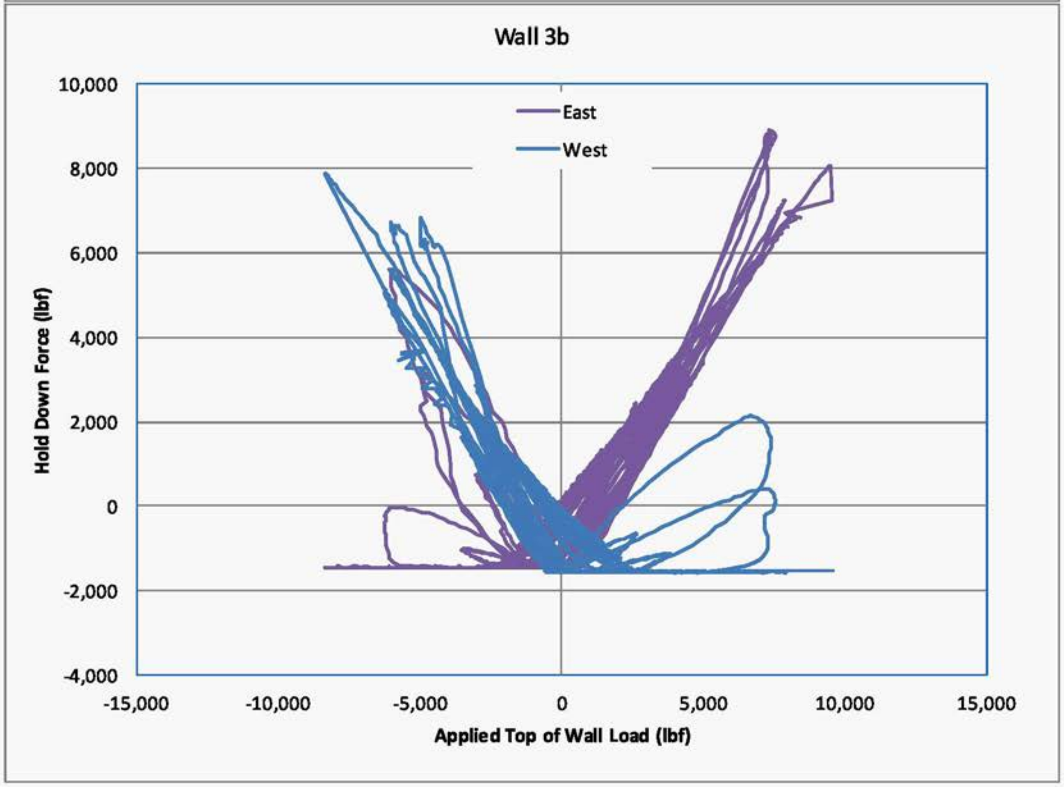


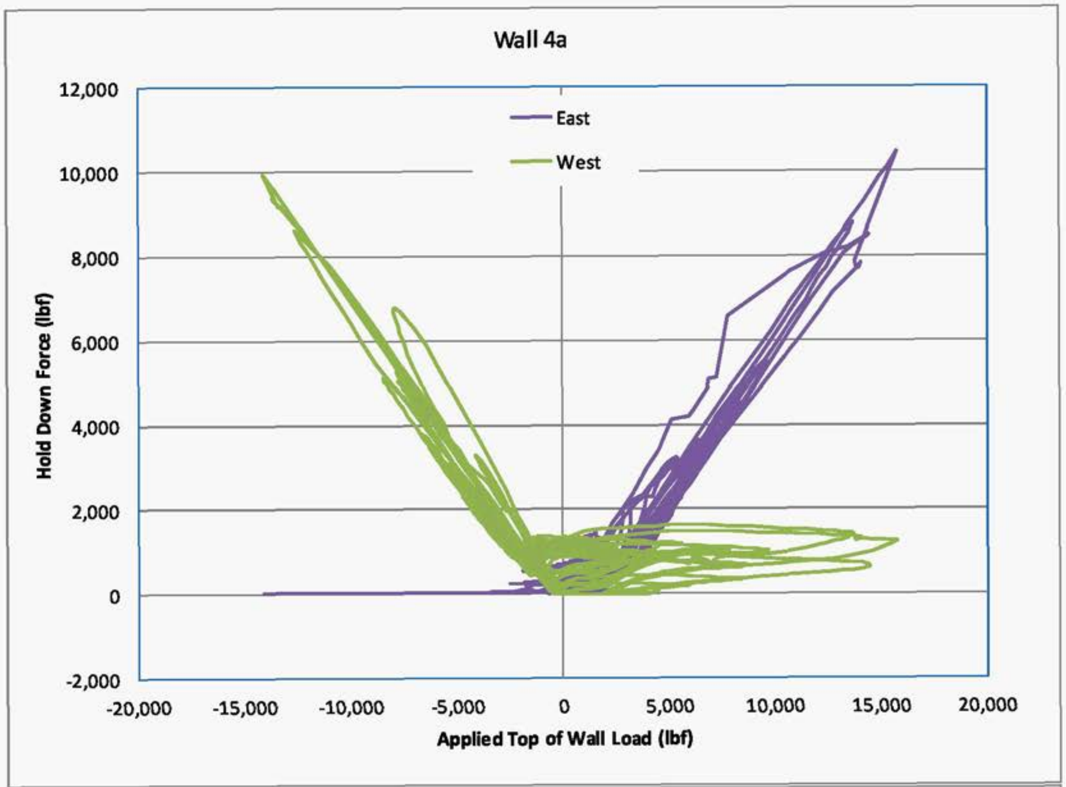


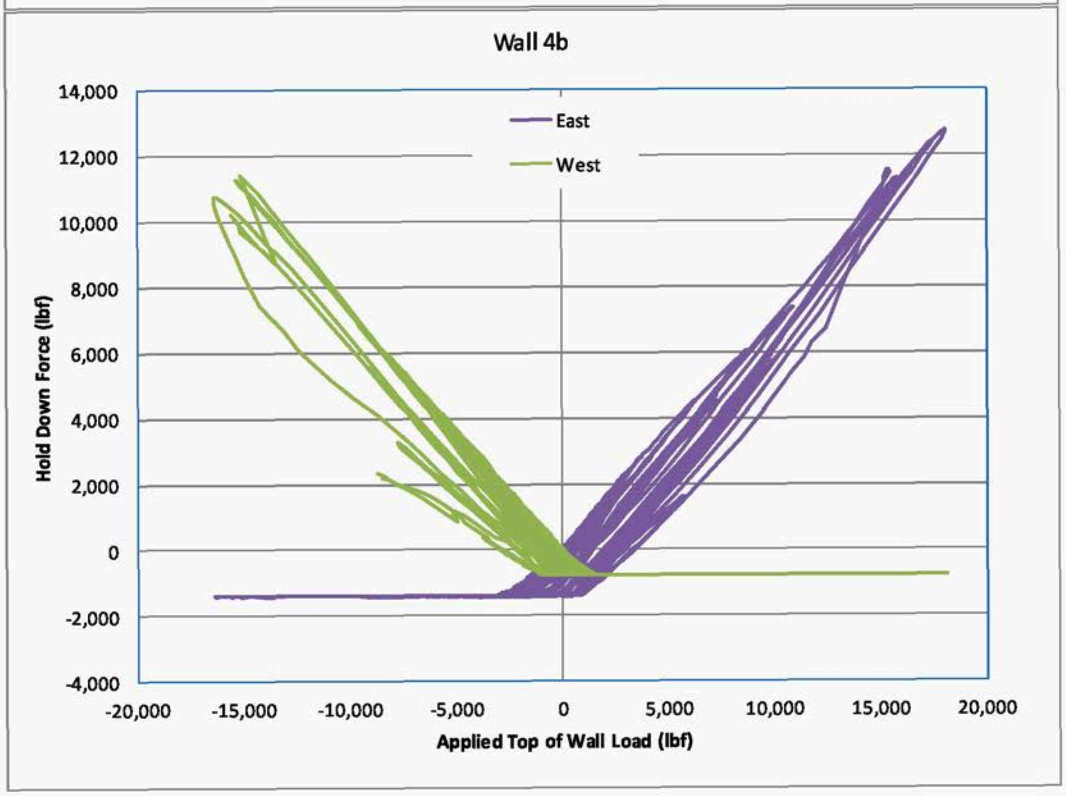

Wall 2a
West
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
-1,000
Hold Down Force (lbf)
-10,000
-8,000
-6,000
-4,000
-2,000
0
2,000
4,000
6,000
8,000
10,000
Applied Top of Wall Load (lbf)

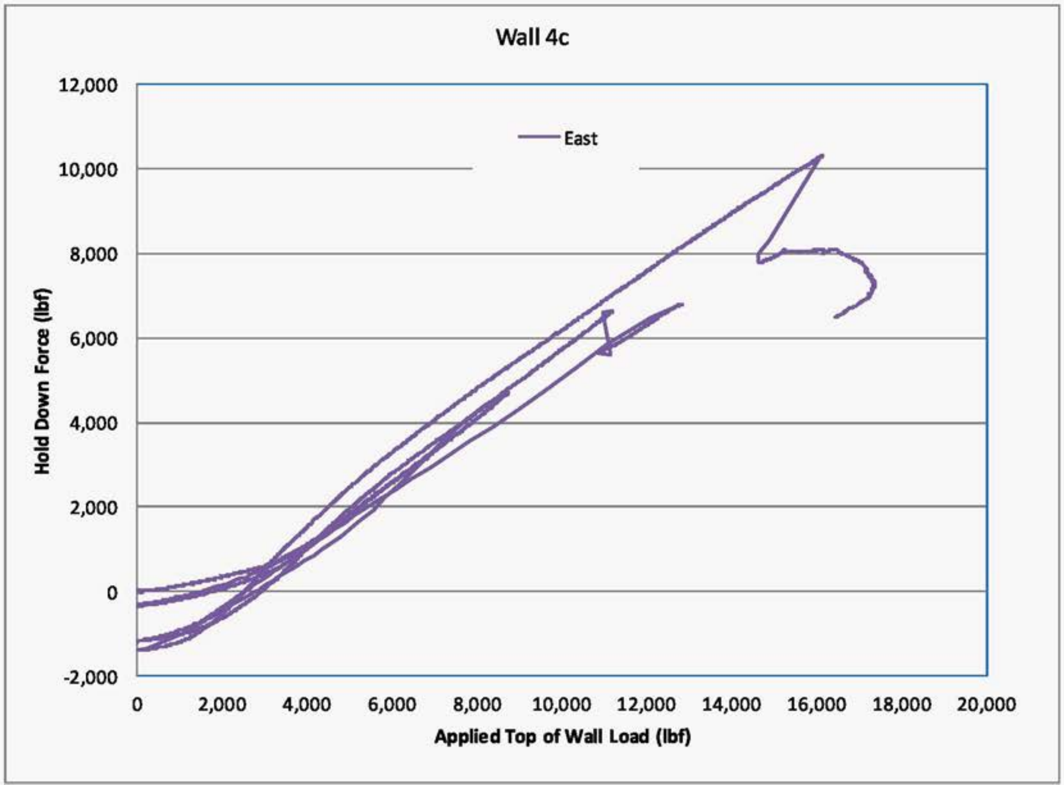

Wall 2b
East
West
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
-1,000
-2,000
-3,000
Hold Down Force (lbf)
-10,000
-8,000
-6,000
-4,000
-2,000
0
2,000
4,000
6,000
8,000
10,000
Applied Top of Wall Load (lbf)

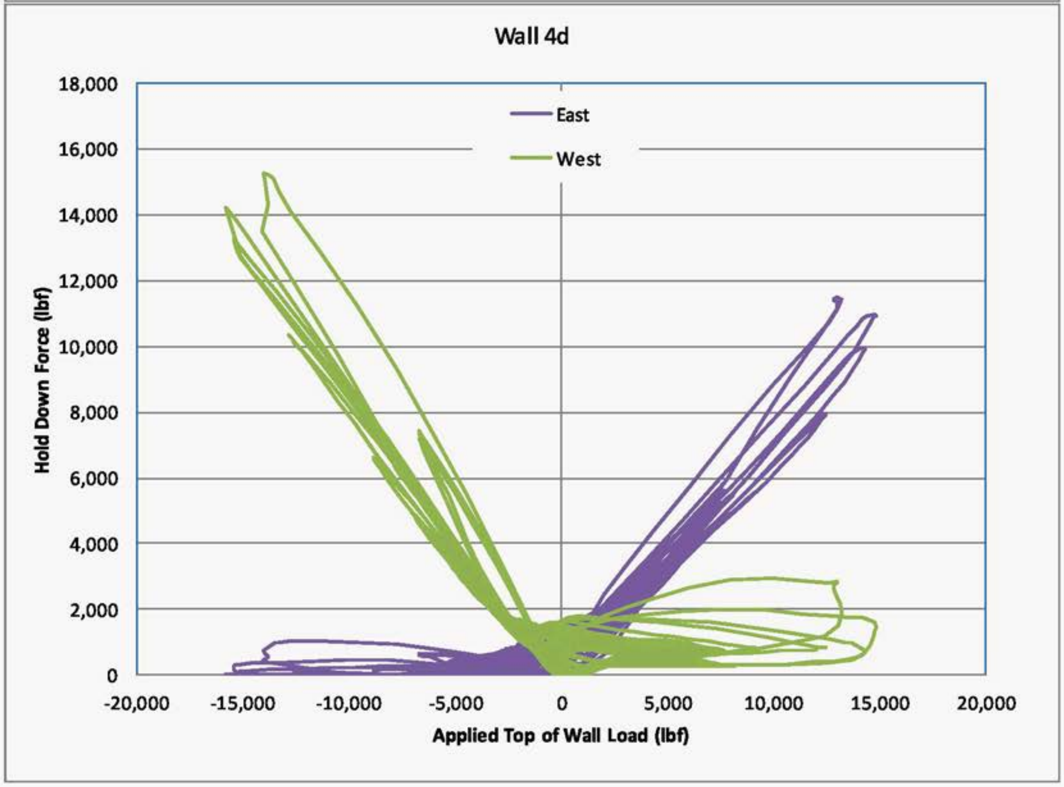

Wall 3a
West
Hold Down Force (lbf)
12,000
10,000
8,000
6,000
4,000
2,000
0
-15,000
-10,000
-5,000
0
5,000
10,000
15,000
Applied Top of Wall Load (lbf)

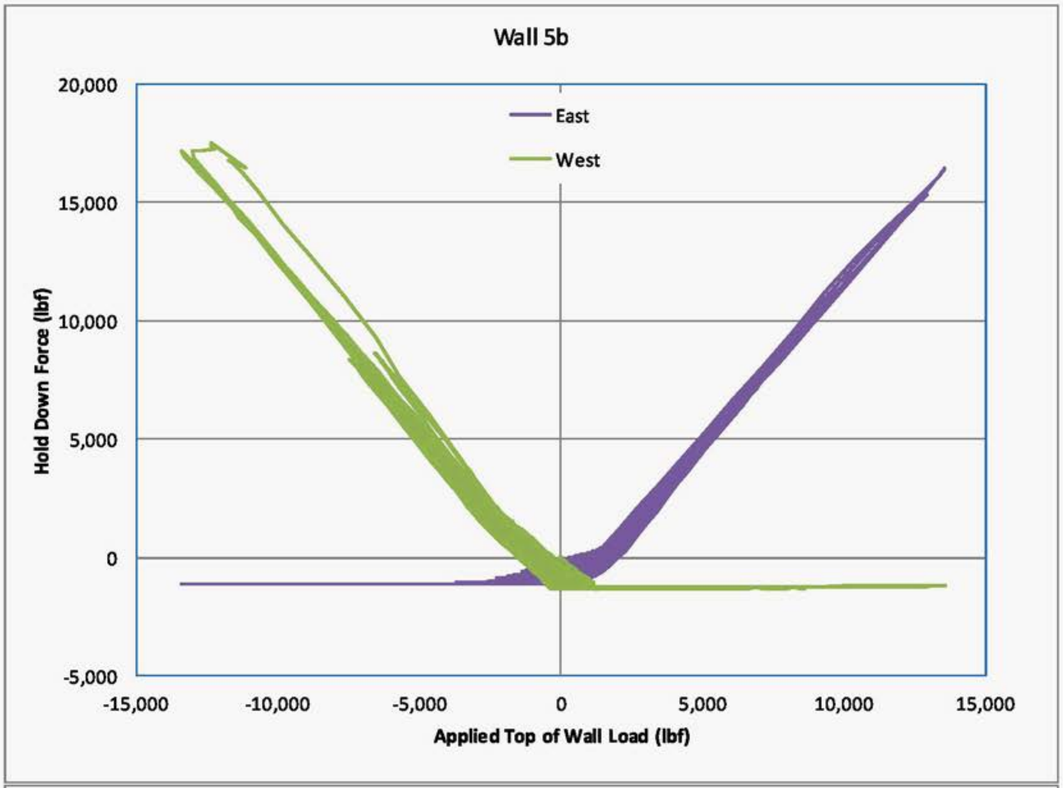

Wall 3b
East
West
Hold Down Force (lbf)
10,000
8,000
6,000
4,000
2,000
0
-2,000
-4,000
-15,000
-10,000
-5,000
0
5,000
10,000
15,000
Applied Top of Wall Load (lbf)

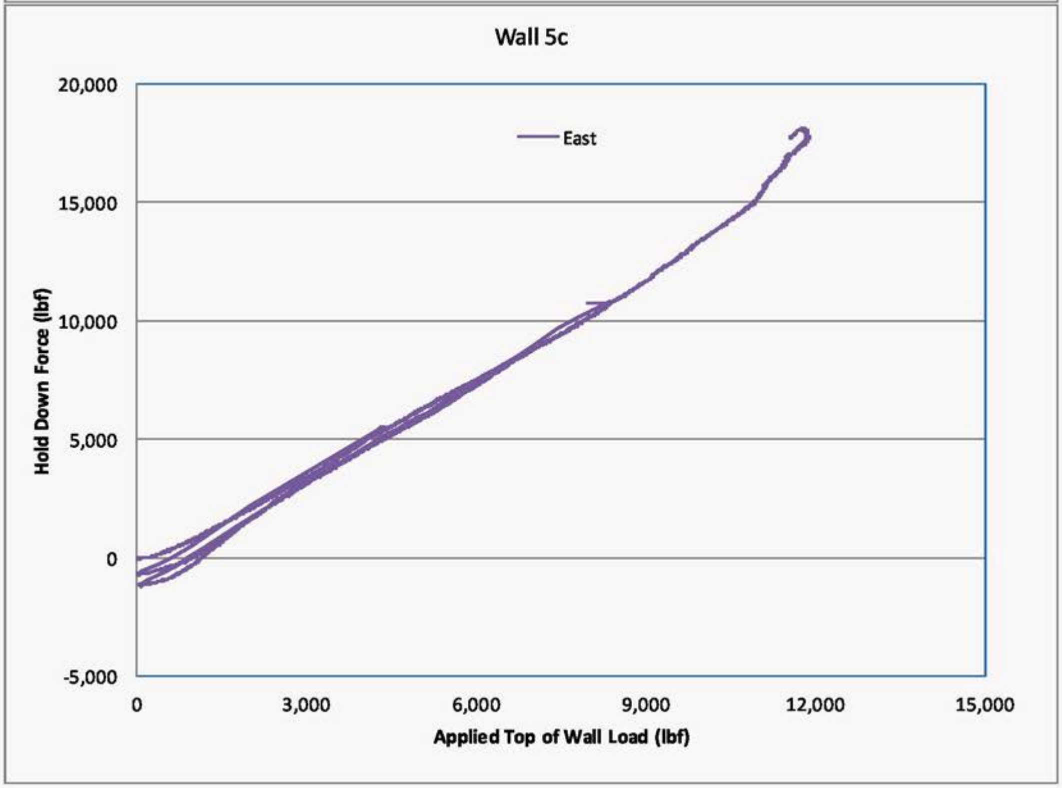

Wall 4a
East
West
12,000
10,000
8,000
6,000
4,000
2,000
0
-2,000
Hold Down Force (lbf)
-20,000
-15,000
-10,000
-5,000
0
5,000
10,000
15,000
20,000
Applied Top of Wall Load (lbf)

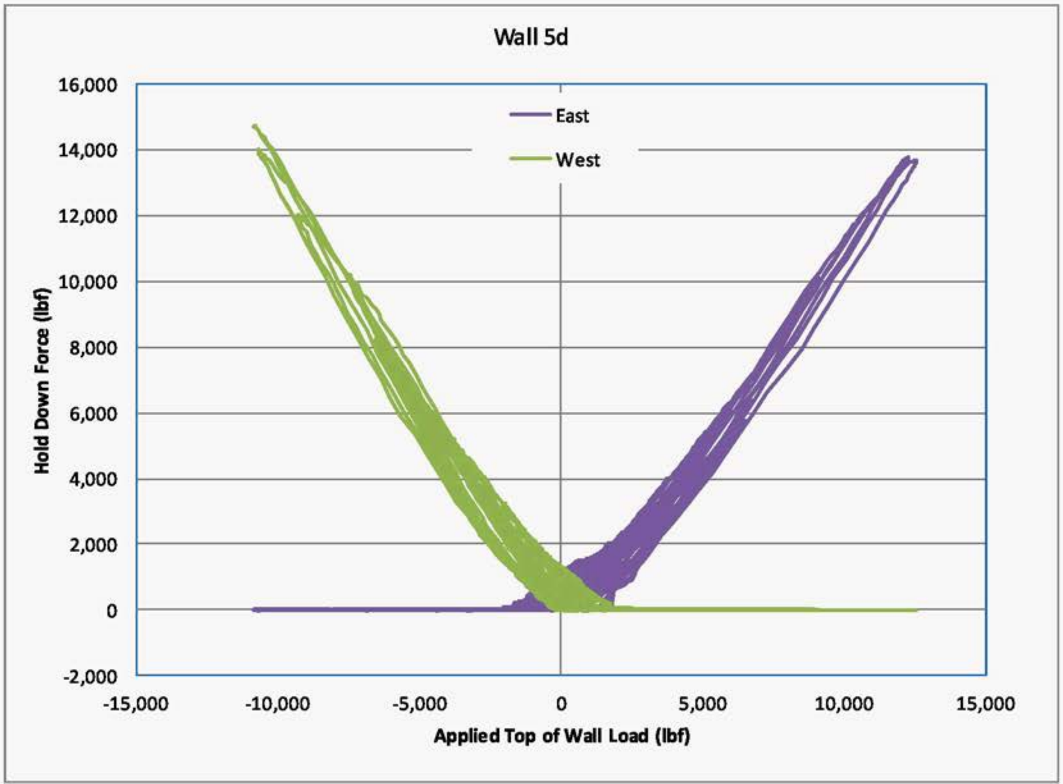

Wall 4b
East
West
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
-2,000
-4,000
Hold Down Force (lbf)
-20,000
-15,000
-10,000
-5,000
0
5,000
10,000
15,000
20,000
Applied Top of Wall Load (lbf)

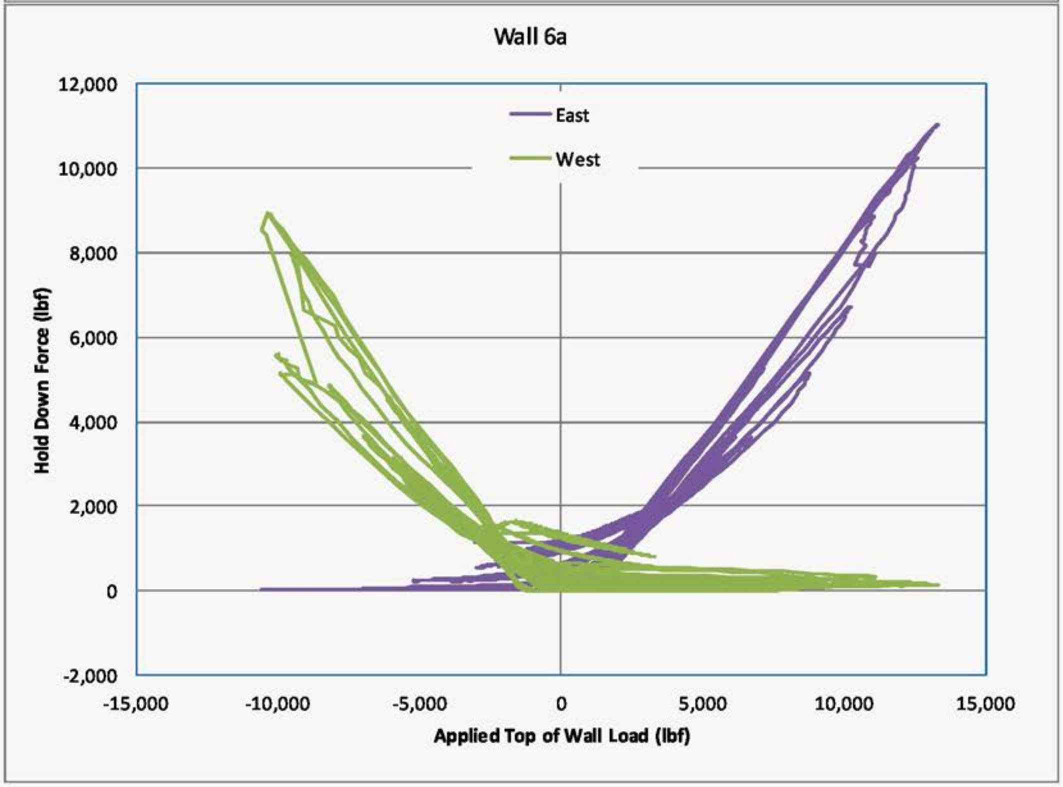

Wall 4c
East
12,000
10,000
8,000
6,000
4,000
2,000
0
-2,000
Hold Down Force (lbf)
0
2,000
4,000
6,000
8,000
10,000
12,000
14,000
16,000
18,000
20,000
Applied Top of Wall Load (lbf)

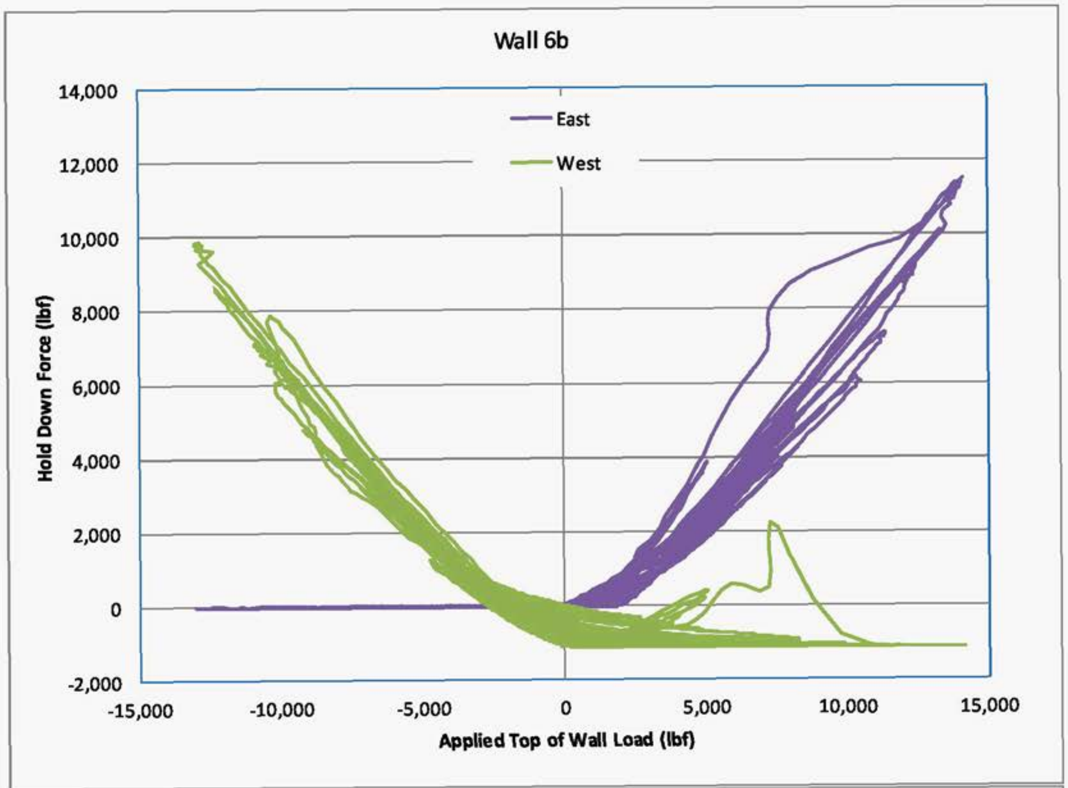

Wall 4d
East
West
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Hold Down Force (lbf)
-20,000
-15,000
-10,000
-5,000
0
5,000
10,000
15,000
20,000
Applied Top of Wall Load (lbf)

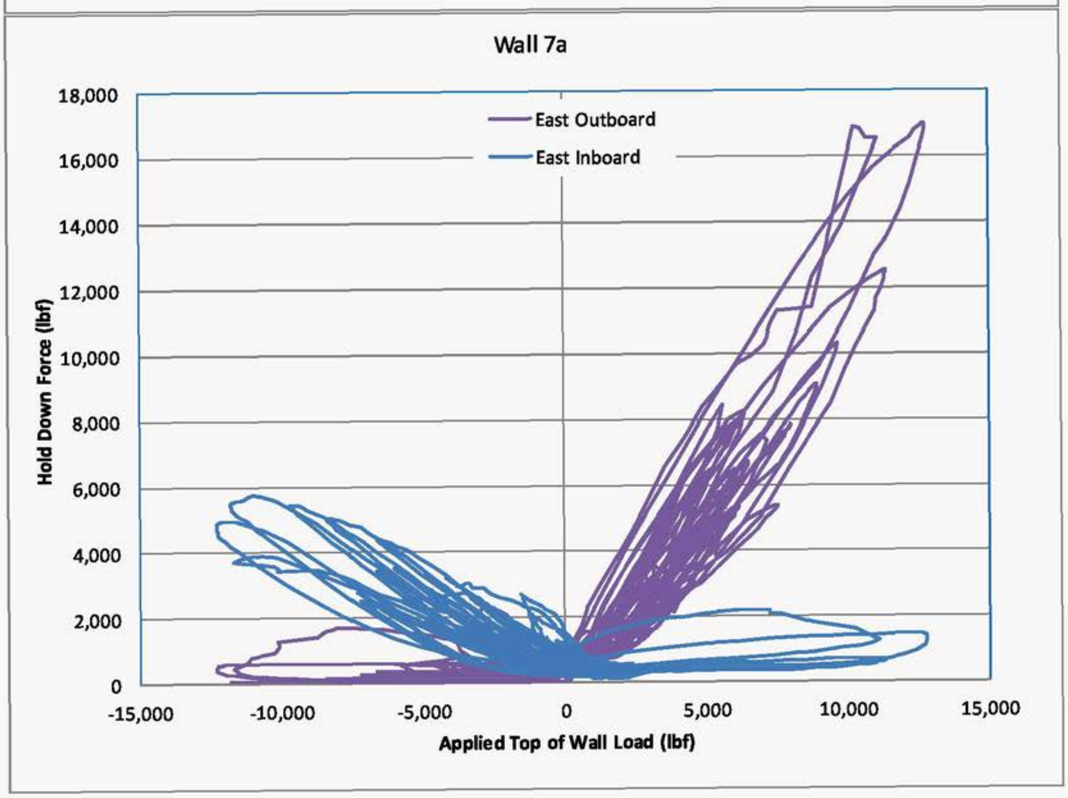

Wall 5b
East
West
20,000
15,000
10,000
5,000
0
-5,000
Hold Down Force (lbf)
-15,000
-10,000
-5,000
0
5,000
10,000
15,000
Applied Top of Wall Load (lbf)

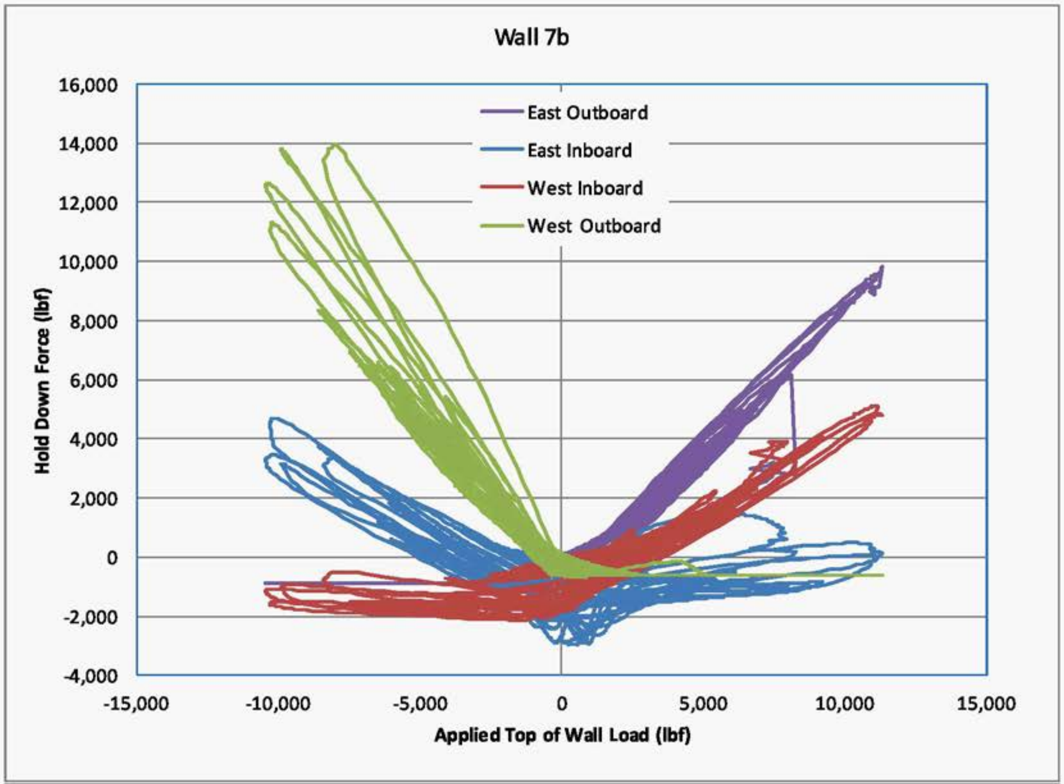

Wall 5c
East
20,000
15,000
10,000
5,000
0
-5,000
Hold Down Force (lbf)
0
3,000
6,000
9,000
12,000
15,000
Applied Top of Wall Load (lbf)

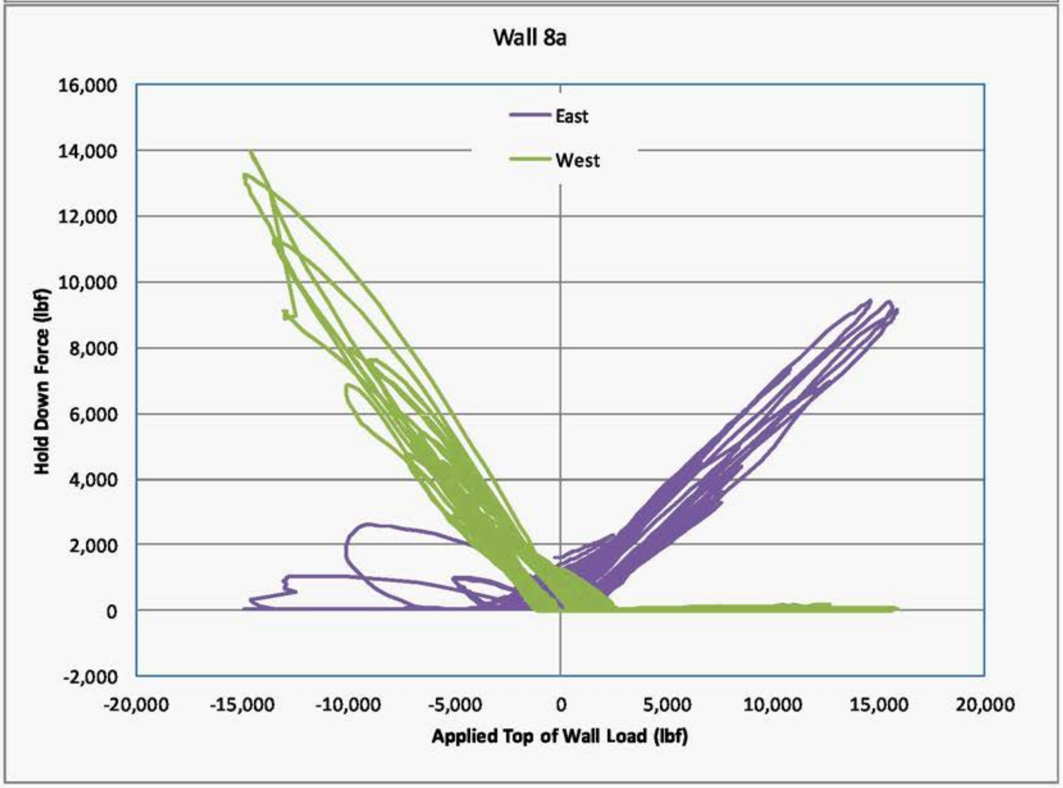

Wall 5d
East
West
Hold Down Force (lbf)
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
-2,000
-15,000
-10,000
-5,000
0
5,000
10,000
15,000
Applied Top of Wall Load (lbf)

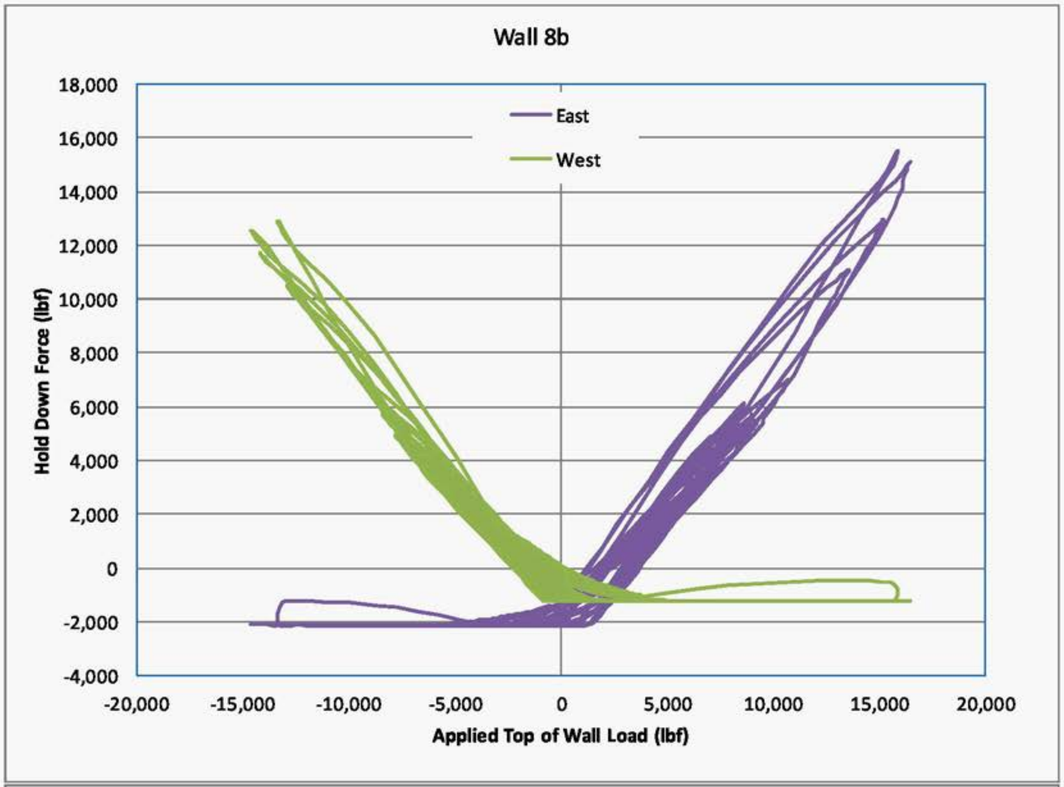

Wall 6a
East
West
Hold Down Force (lbf)
12,000
10,000
8,000
6,000
4,000
2,000
0
-2,000
-15,000
-10,000
-5,000
0
5,000
10,000
15,000
Applied Top of Wall Load (lbf)


Wall 6b
East
West
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
-2,000
Hold Down Force (lbf)
-15,000
-10,000
-5,000
0
5,000
10,000
15,000
Applied Top of Wall Load (lbf)

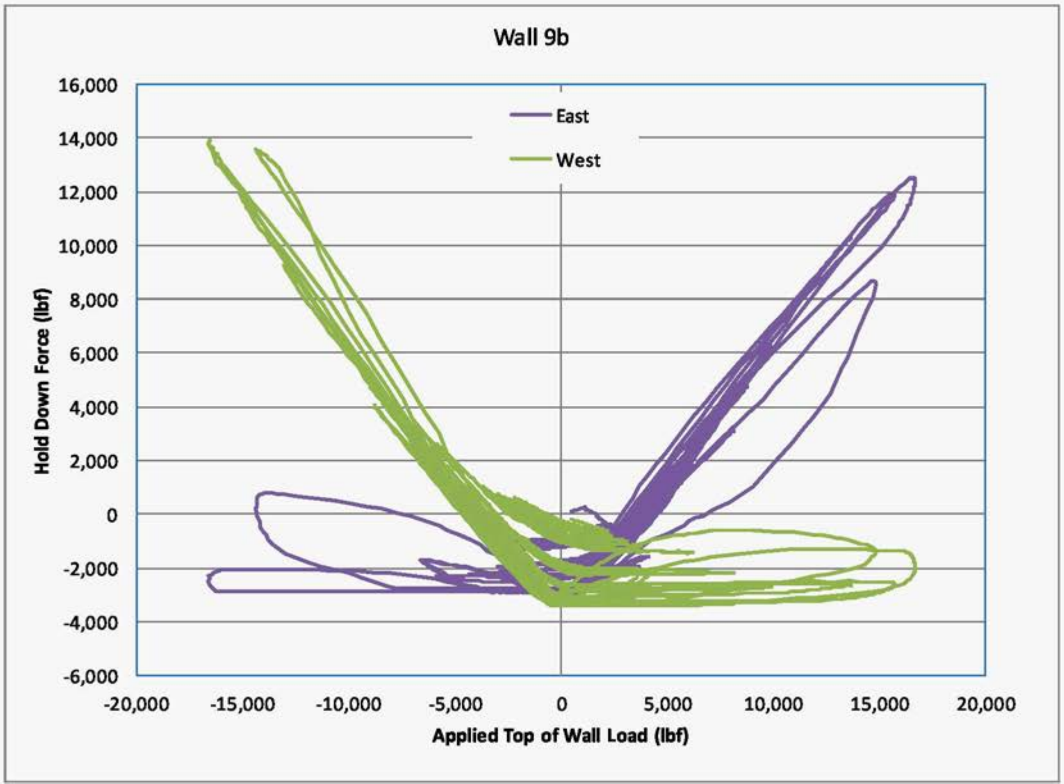

Wall 7a
East Outboard
East Inboard
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Hold Down Force (lbf)
-15,000
-10,000
-5,000
0
5,000
10,000
15,000
Applied Top of Wall Load (lbf)

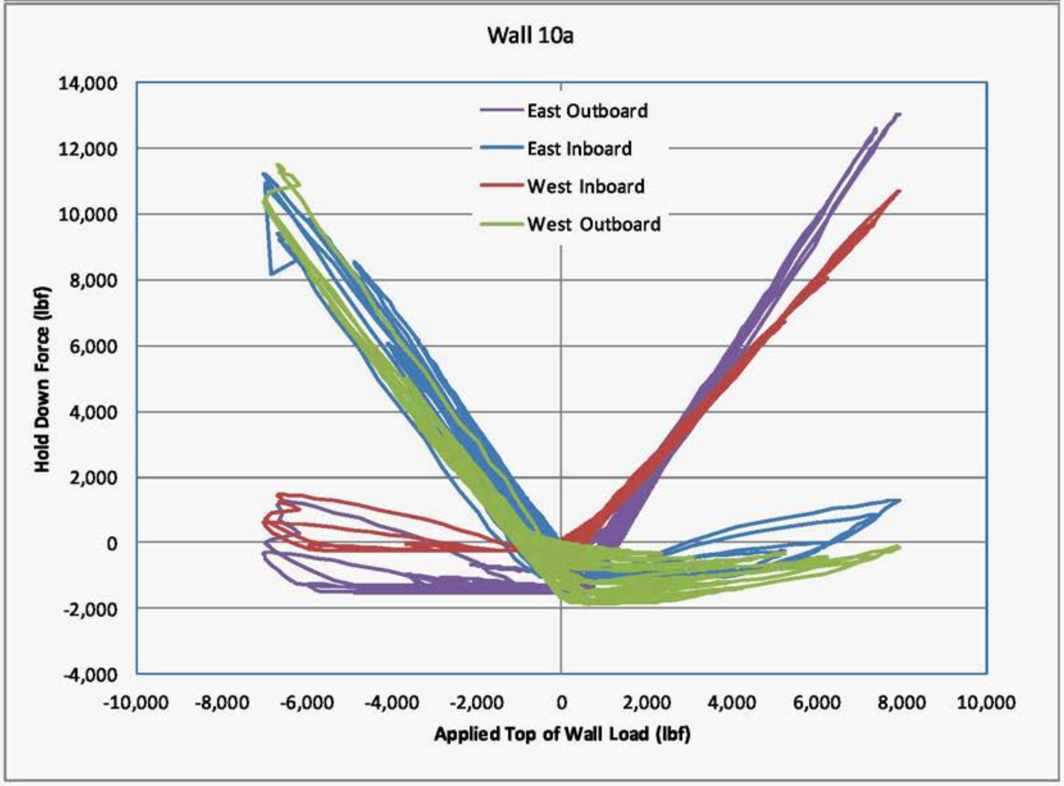

Wall 7b
East Outboard
East Inboard
West Inboard
West Outboard
Hold Down Force (lbf)
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
-2,000
-4,000
-15,000
-10,000
-5,000
0
5,000
10,000
15,000
Applied Top of Wall Load (lbf)

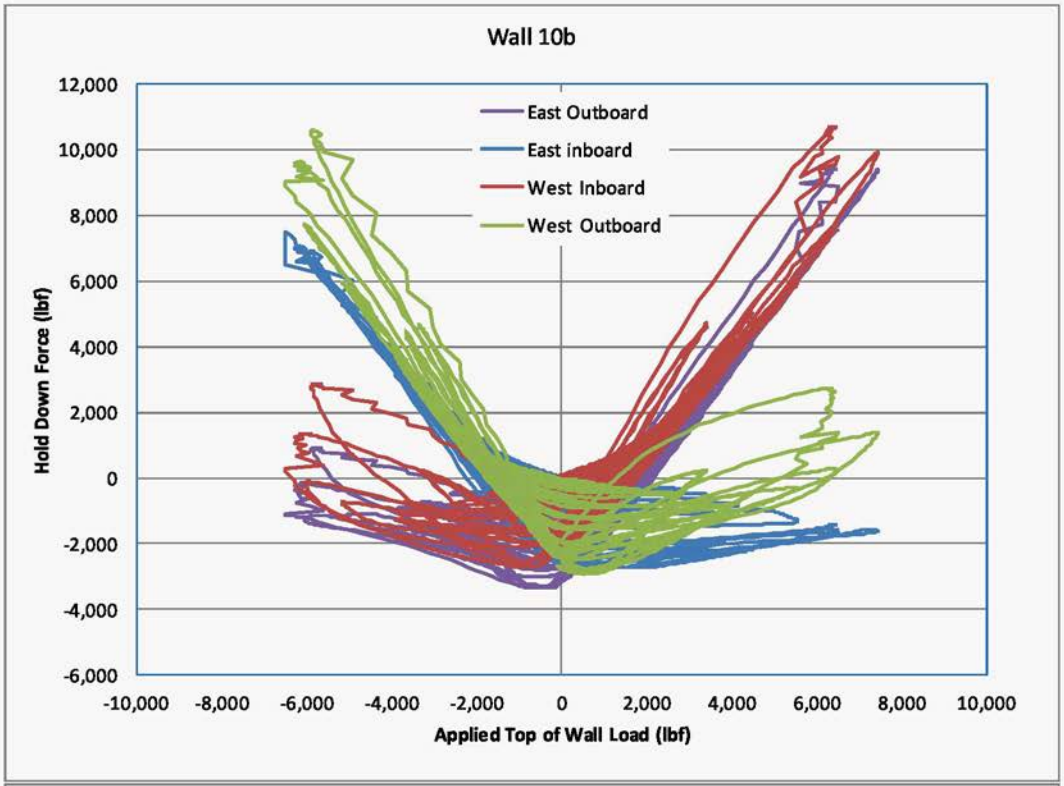

Wall 8a
East
West
Hold Down Force (lbf)
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
-2,000
-20,000
-15,000
-10,000
-5,000
0
5,000
10,000
15,000
20,000
Applied Top of Wall Load (lbf)

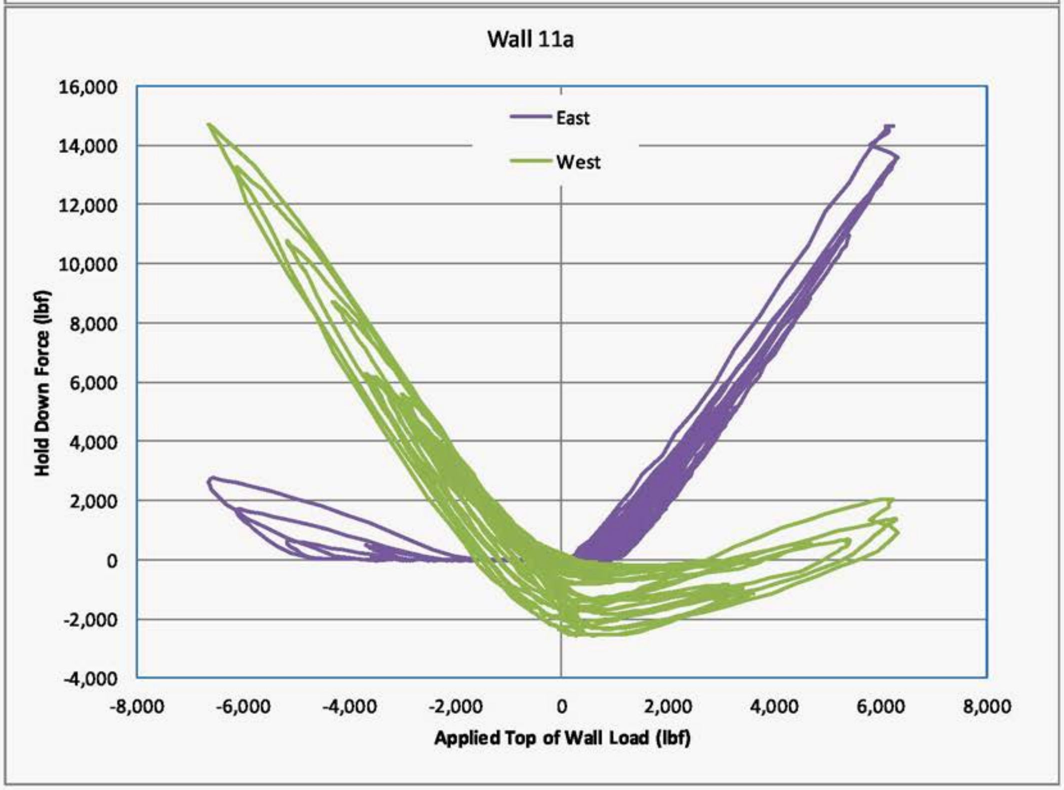

Wall 8b
East
West
Hold Down Force (lbf)
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
-2,000
-4,000
-20,000
-15,000
-10,000
-5,000
0
5,000
10,000
15,000
20,000
Applied Top of Wall Load (lbf)

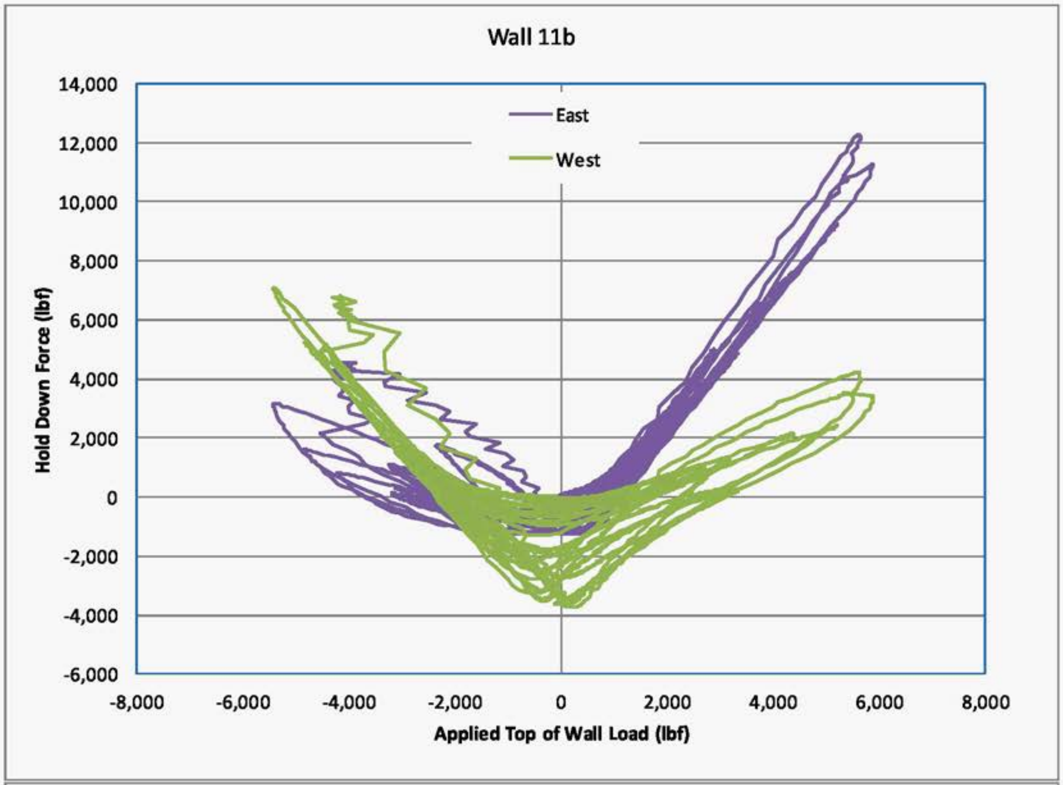

Wall 9a
East
West
Hold Down Force (lbf)
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
-2,000
-4,000
-20,000
-15,000
-10,000
-5,000
0
5,000
10,000
15,000
20,000
Applied Top of Wall Load (lbf)

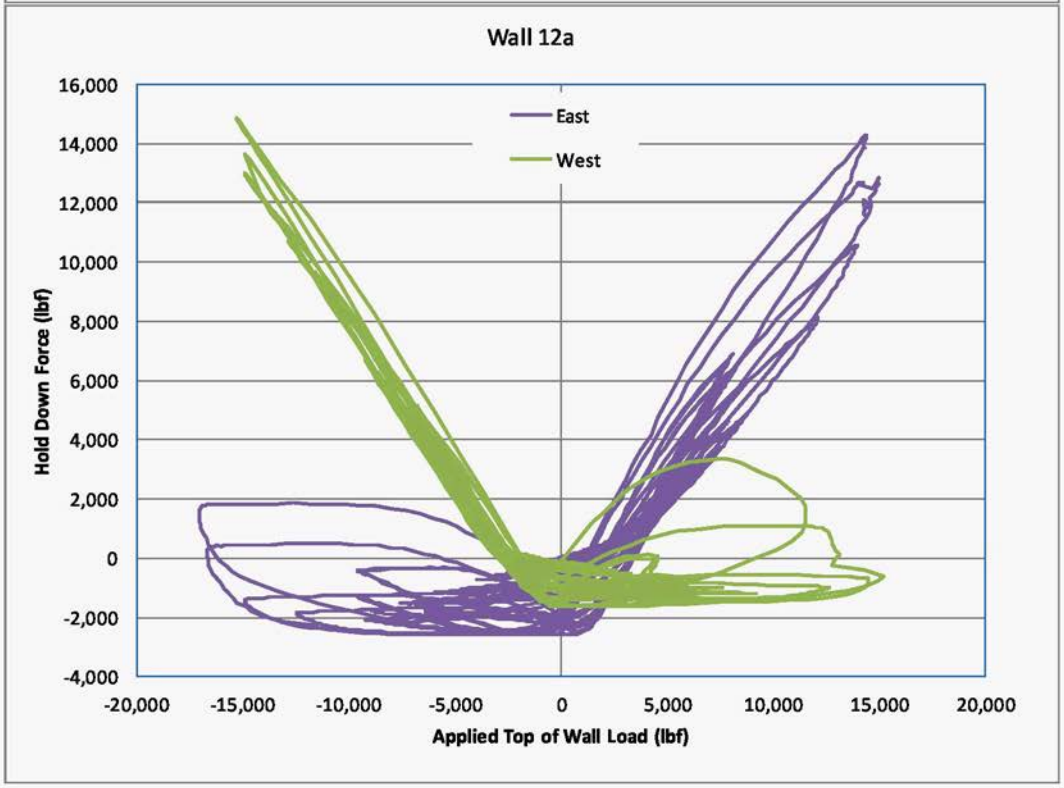

Wall 9b
East
West
Hold Down Force (lbf)
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
-2,000
-4,000
-6,000
-20,000
-15,000
-10,000
-5,000
0
5,000
10,000
15,000
20,000
Applied Top of Wall Load (lbf)

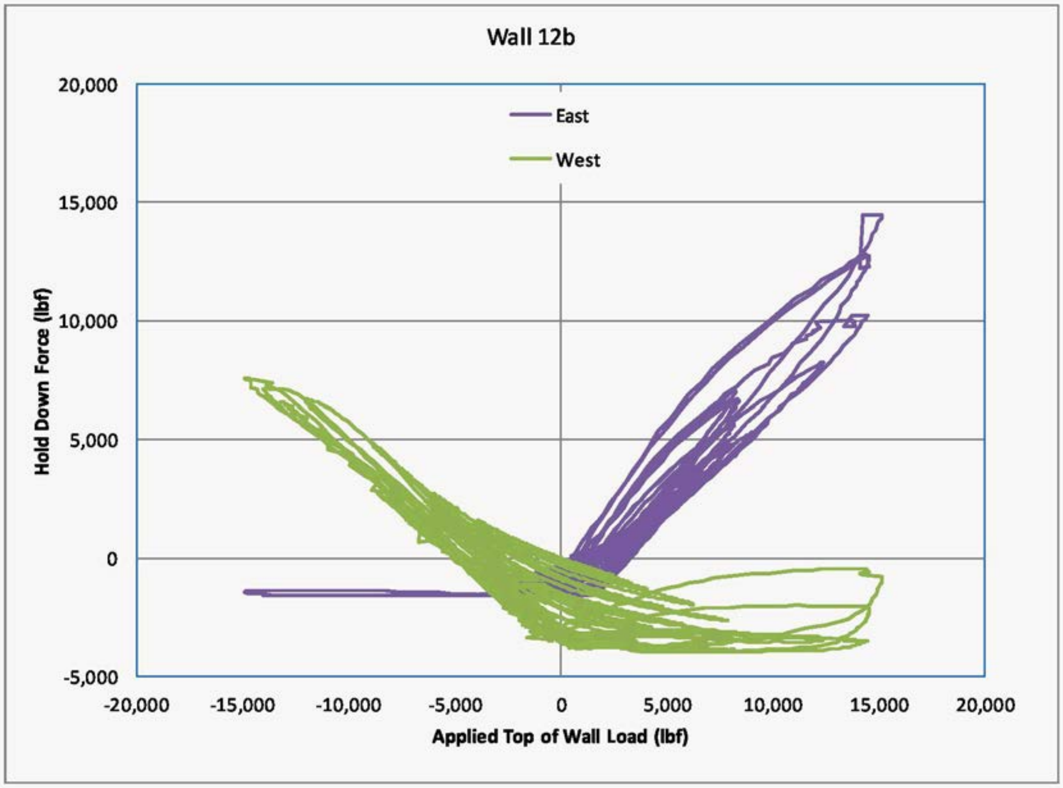

Wall 10a
East Outboard
East Inboard
West Inboard
West Outboard
Hold Down Force (lbf)
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
-2,000
-4,000
-10,000
-8,000
-6,000
-4,000
-2,000
0
2,000
4,000
6,000
8,000
10,000
Applied Top of Wall Load (lbf)


Wall 10b
East Outboard
East inboard
West Inboard
West Outboard
Hold Down Force (lbf)
Applied Top of Wall Load (lbf)
12,000
10,000
8,000
6,000
4,000
2,000
0
-2,000
-4,000
-6,000
-10,000
-8,000
-6,000
-4,000
-2,000
0
2,000
4,000
6,000
8,000
10,000

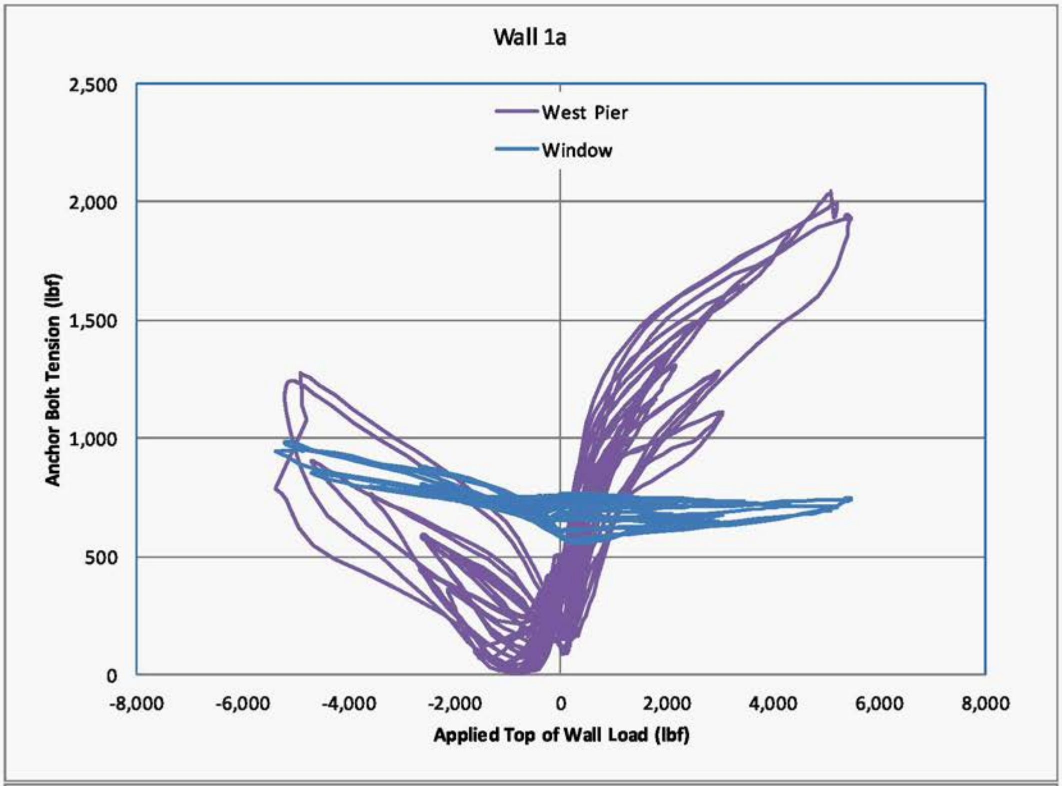

Wall 11a
East
West
Hold Down Force (lbf)
Applied Top of Wall Load (lbf)
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
-2,000
-4,000
-8,000
-6,000
-4,000
-2,000
0
2,000
4,000
6,000
8,000

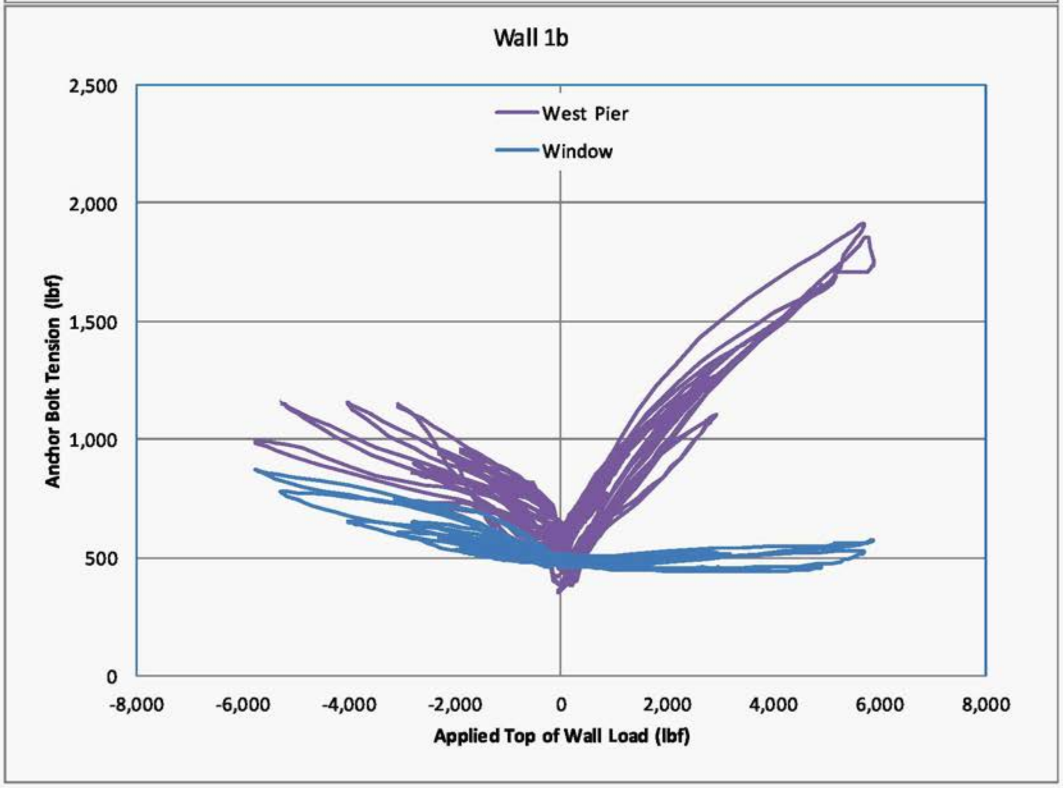

Wall 11b
East
West
Hold Down Force (lbf)
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
-2,000
-4,000
-6,000
-8,000
-6,000
-4,000
-2,000
0
2,000
4,000
6,000
8,000
Applied Top of Wall Load (lbf)

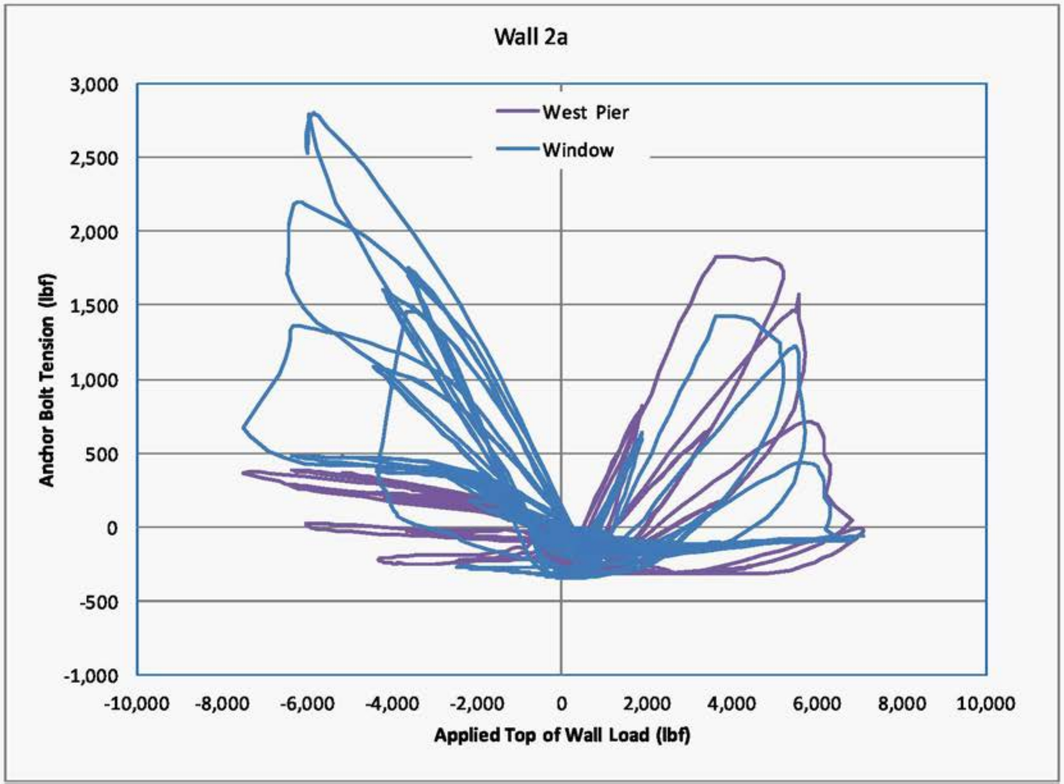

Wall 12a
East
West
Hold Down Force (lbf)
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
-2,000
-4,000
-20,000
-15,000
-10,000
-5,000
0
5,000
10,000
15,000
20,000
Applied Top of Wall Load (lbf)

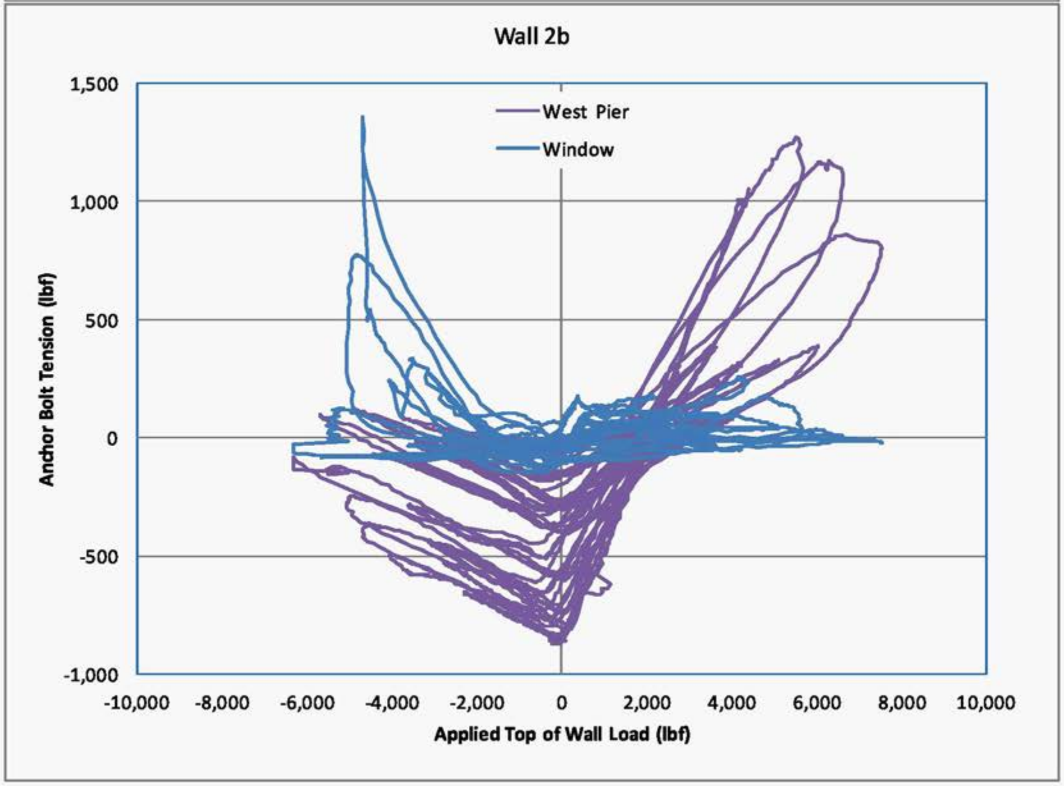

Wall 12b
East
West
Hold Down Force (lbf)
20,000
15,000
10,000
5,000
0
-5,000
-20,000
-15,000
-10,000
-5,000
0
5,000
10,000
15,000
20,000
Applied Top of Wall Load (lbf)

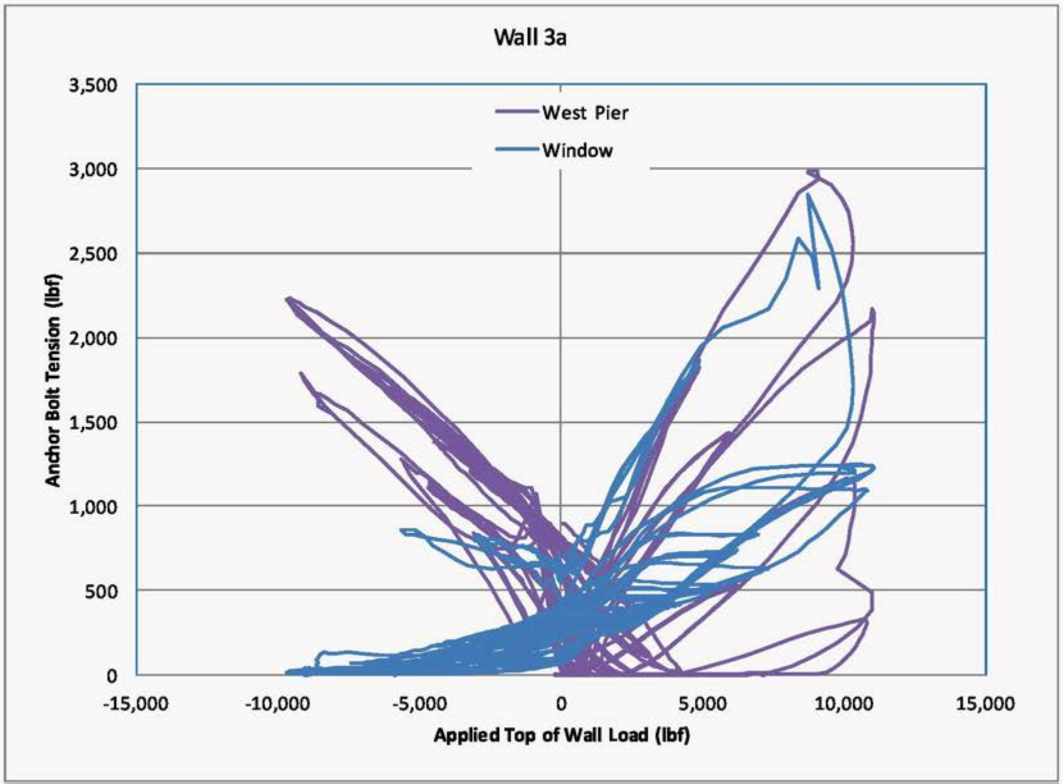
APPENDIX D – ANCHOR BOLT FORCES

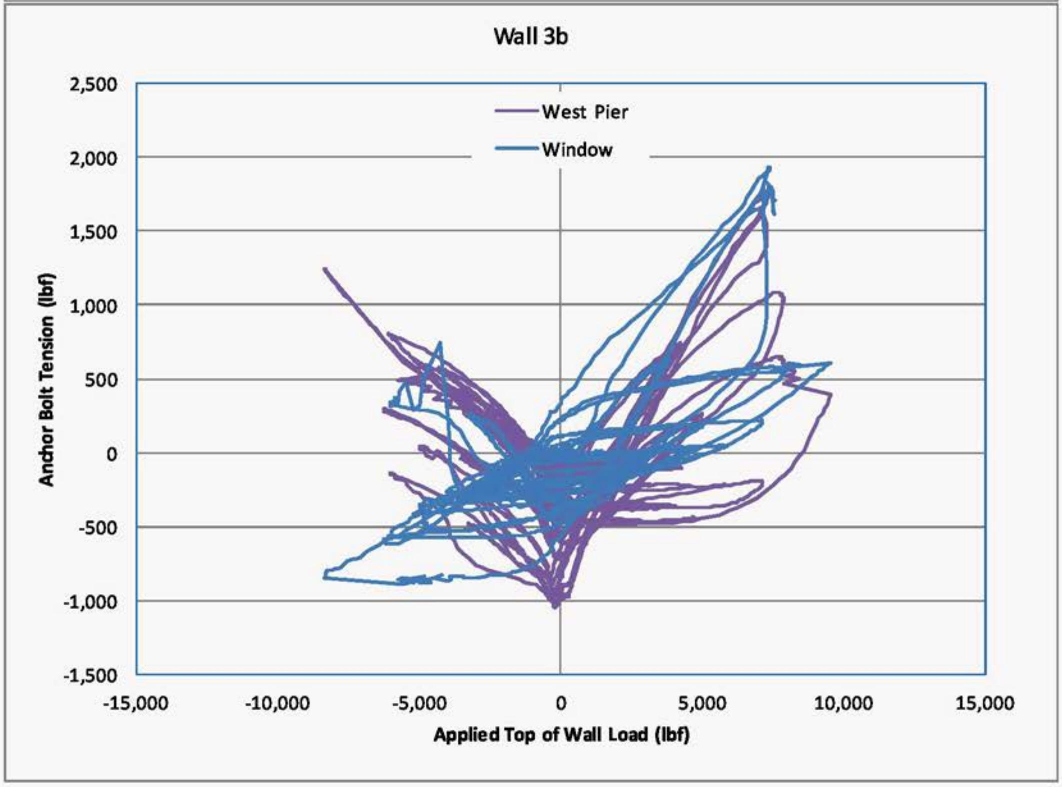


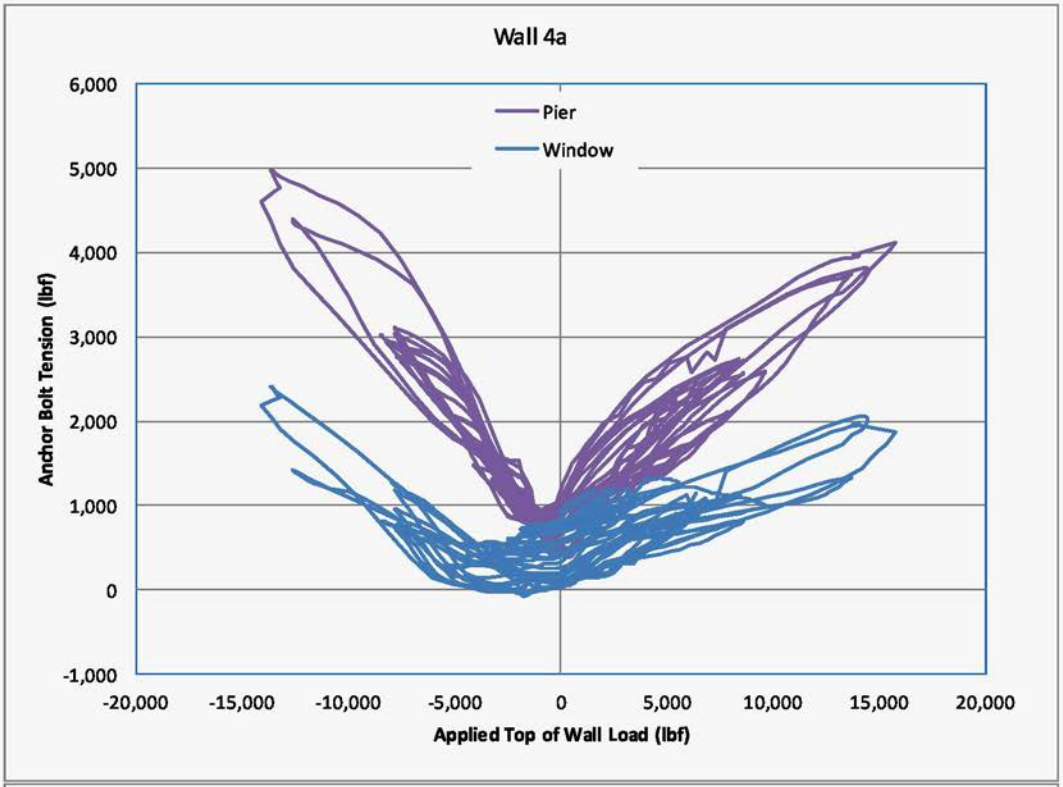


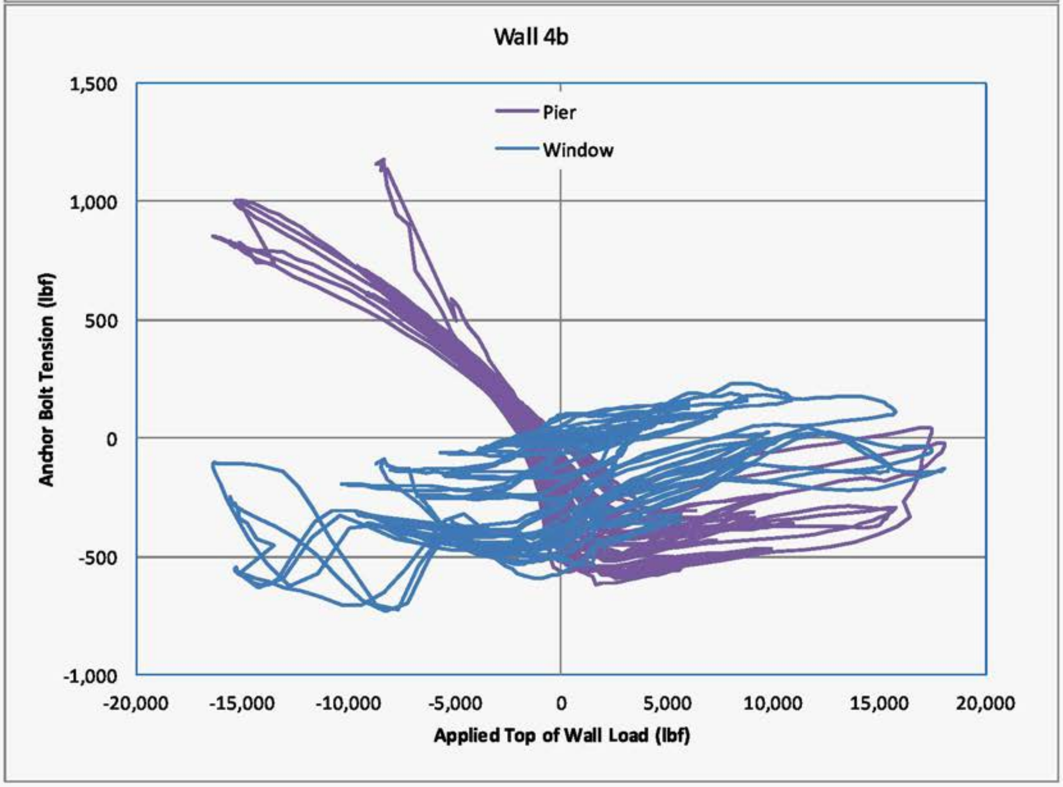

Wall 2a
West Pier
Window
Anchor Bolt Tension (lbf)
3,000
2,500
2,000
1,500
1,000
500
0
-500
-1,000
-10,000
-8,000
-6,000
-4,000
-2,000
0
2,000
4,000
6,000
8,000
10,000
Applied Top of Wall Load (lbf)

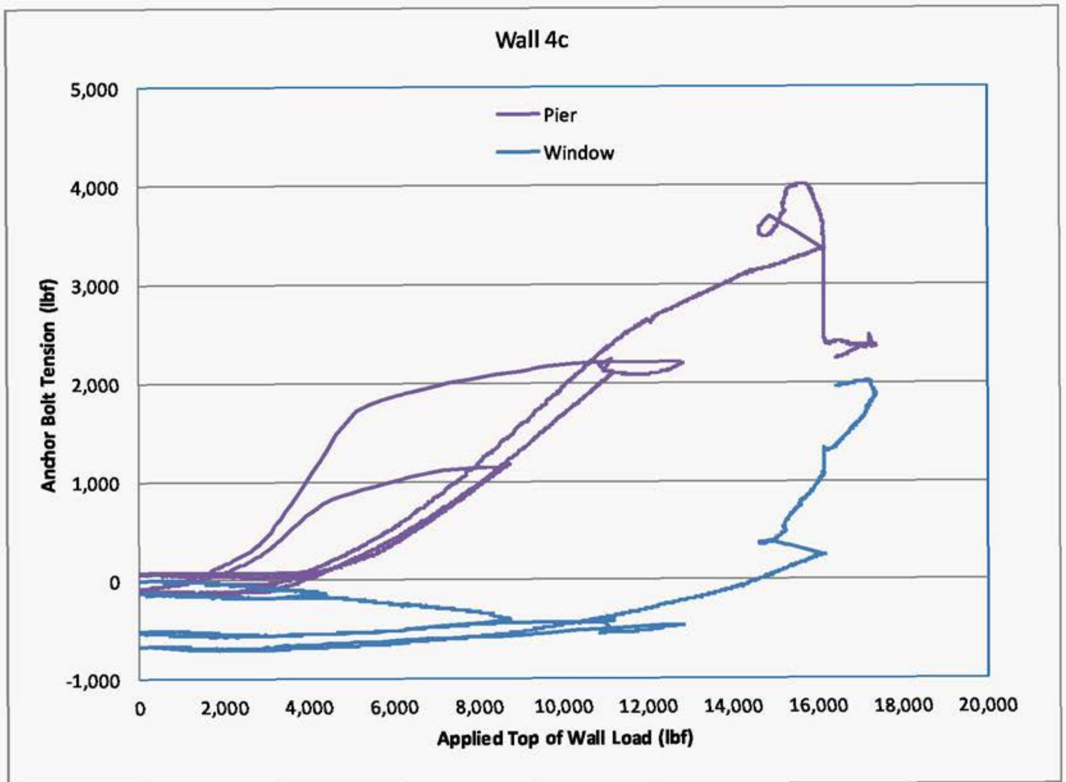

Wall 2b
West Pier
Window
Anchor Bolt Tension (lbf)
1,500
1,000
500
0
-500
-1,000
-10,000
-8,000
-6,000
-4,000
-2,000
0
2,000
4,000
6,000
8,000
10,000
Applied Top of Wall Load (lbf)

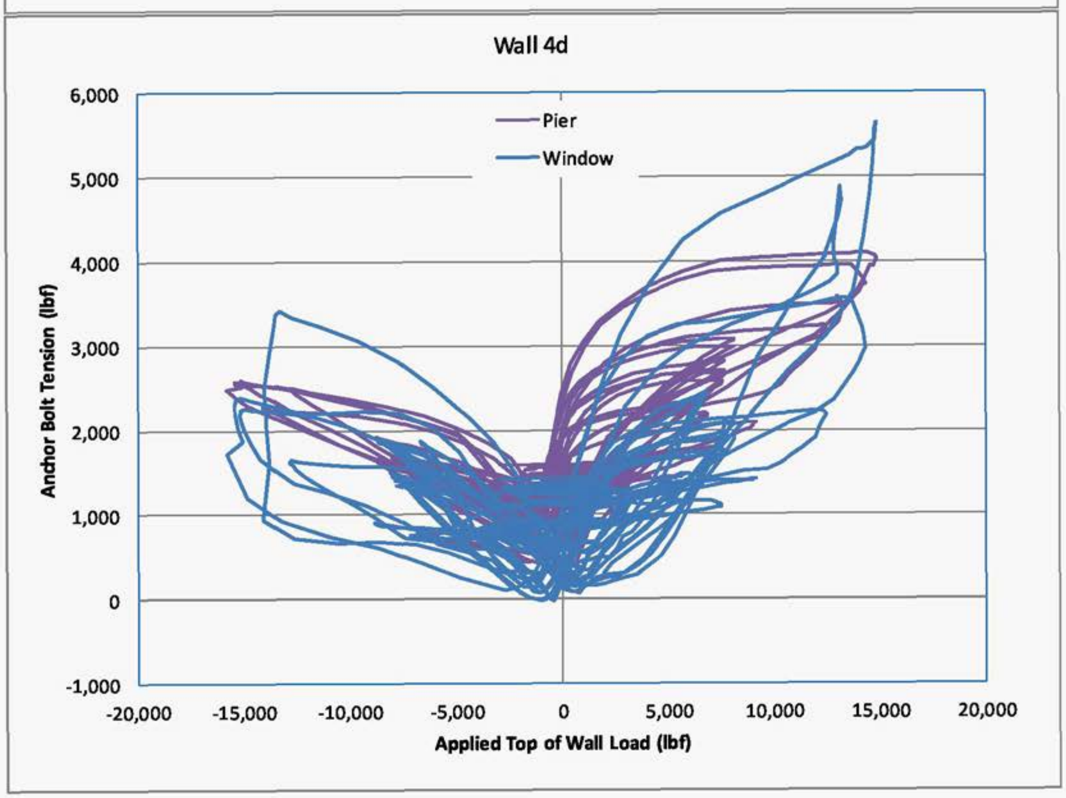

Wall 3a
West Pier
Window
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Anchor Bolt Tension (lbf)
-15,000
-10,000
-5,000
0
5,000
10,000
15,000
Applied Top of Wall Load (lbf)

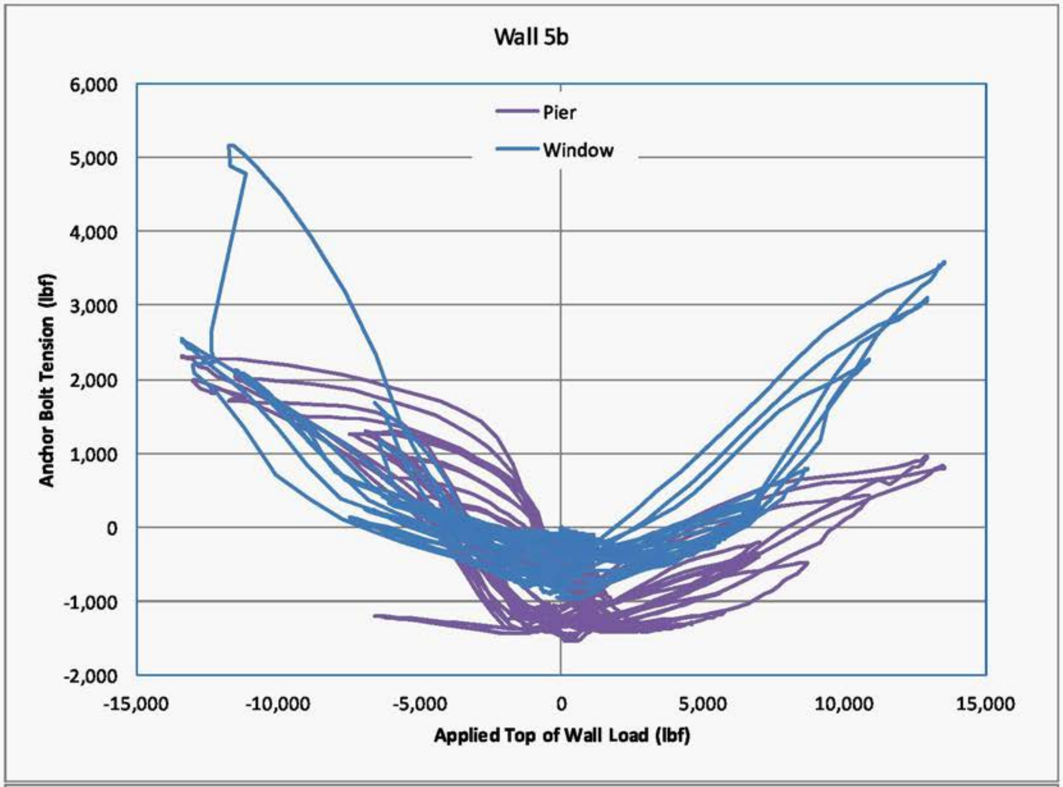

Wall 3b
West Pier
Window
2,500
2,000
1,500
1,000
500
0
-500
-1,000
-1,500
Anchor Bolt Tension (lbf)
-15,000
-10,000
-5,000
0
5,000
10,000
15,000
Applied Top of Wall Load (lbf)

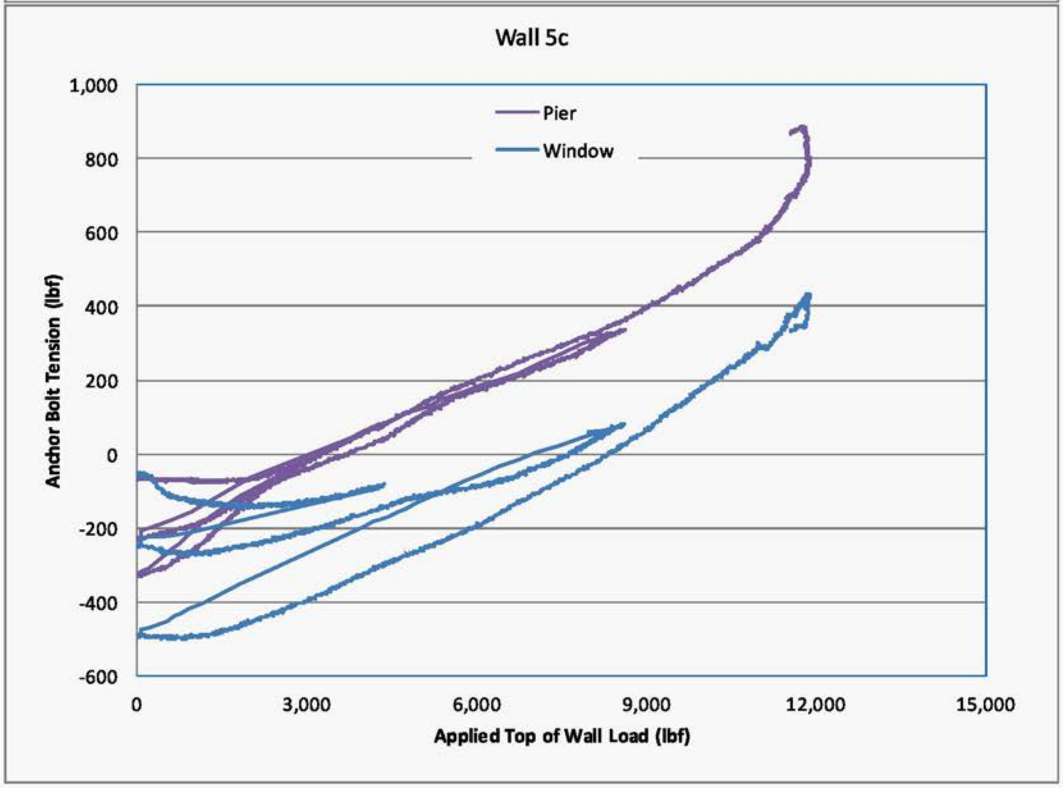

Wall 4a
Pier
Window
6,000
5,000
4,000
3,000
2,000
1,000
0
-1,000
Anchor Bolt Tension (lbf)
-20,000
-15,000
-10,000
-5,000
0
5,000
10,000
15,000
20,000
Applied Top of Wall Load (lbf)

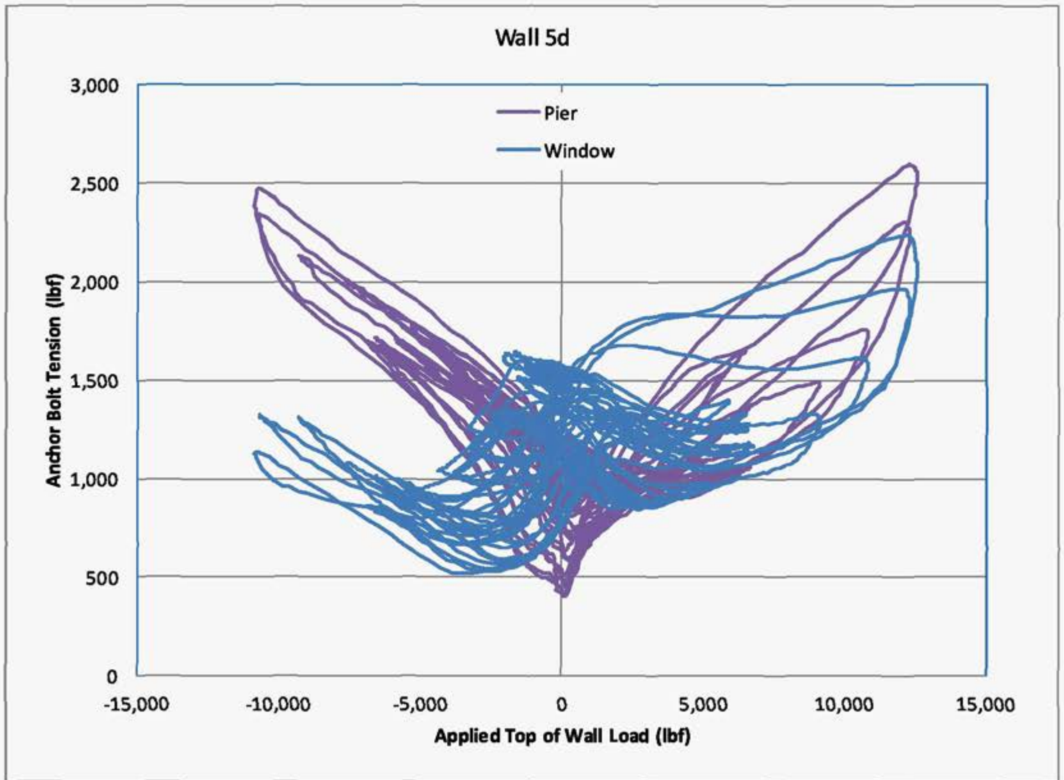

Wall 4b
Pier
Window
1,500
1,000
500
0
-500
-1,000
Anchor Bolt Tension (lbf)
-20,000
-15,000
-10,000
-5,000
0
5,000
10,000
15,000
20,000
Applied Top of Wall Load (lbf)

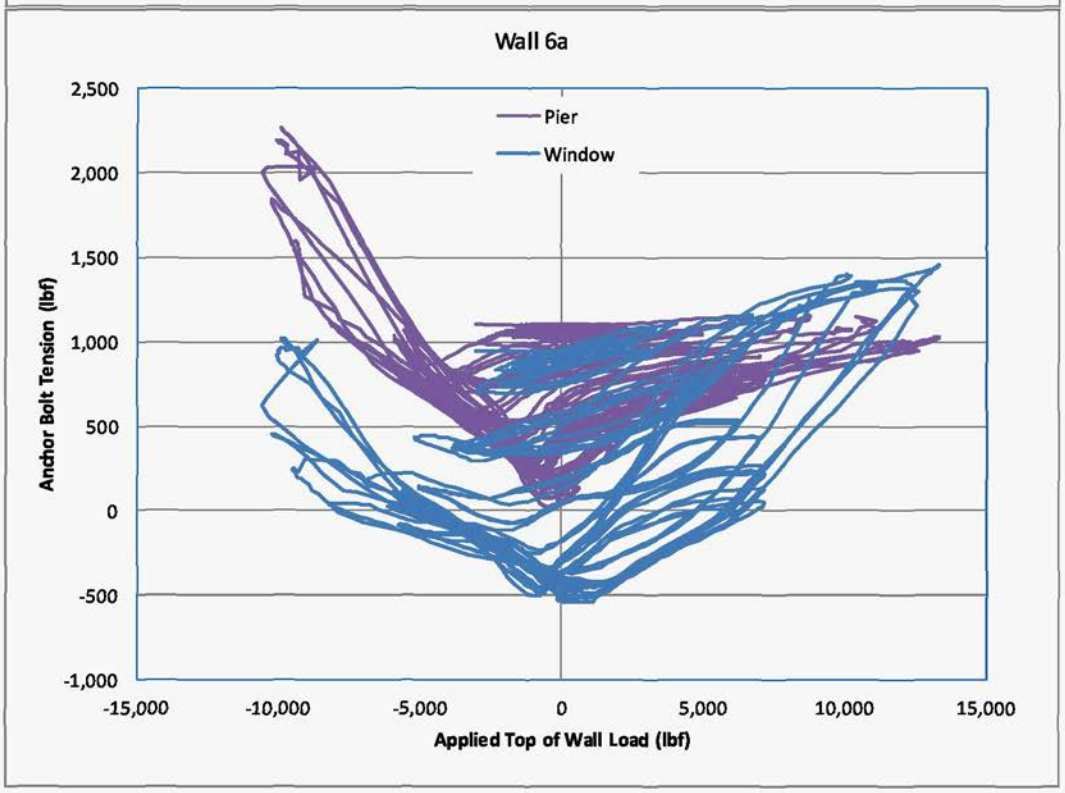

Wall 4c
Pier
Window
Anchor Bolt Tension (lbf)
5,000
4,000
3,000
2,000
1,000
0
-1,000
0
2,000
4,000
6,000
8,000
10,000
12,000
14,000
16,000
18,000
20,000
Applied Top of Wall Load (lbf)

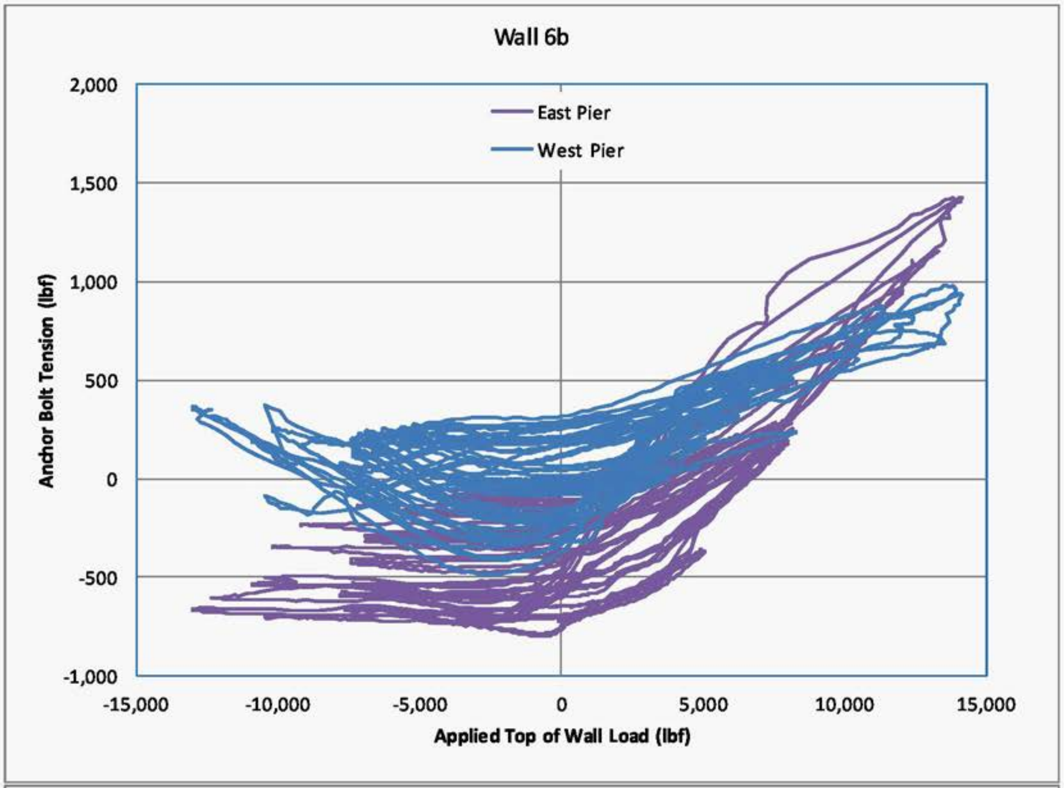

Wall 4d
Pier
Window
Anchor Bolt Tension (lbf)
6,000
5,000
4,000
3,000
2,000
1,000
0
-1,000
-20,000
-15,000
-10,000
-5,000
0
5,000
10,000
15,000
20,000
Applied Top of Wall Load (lbf)

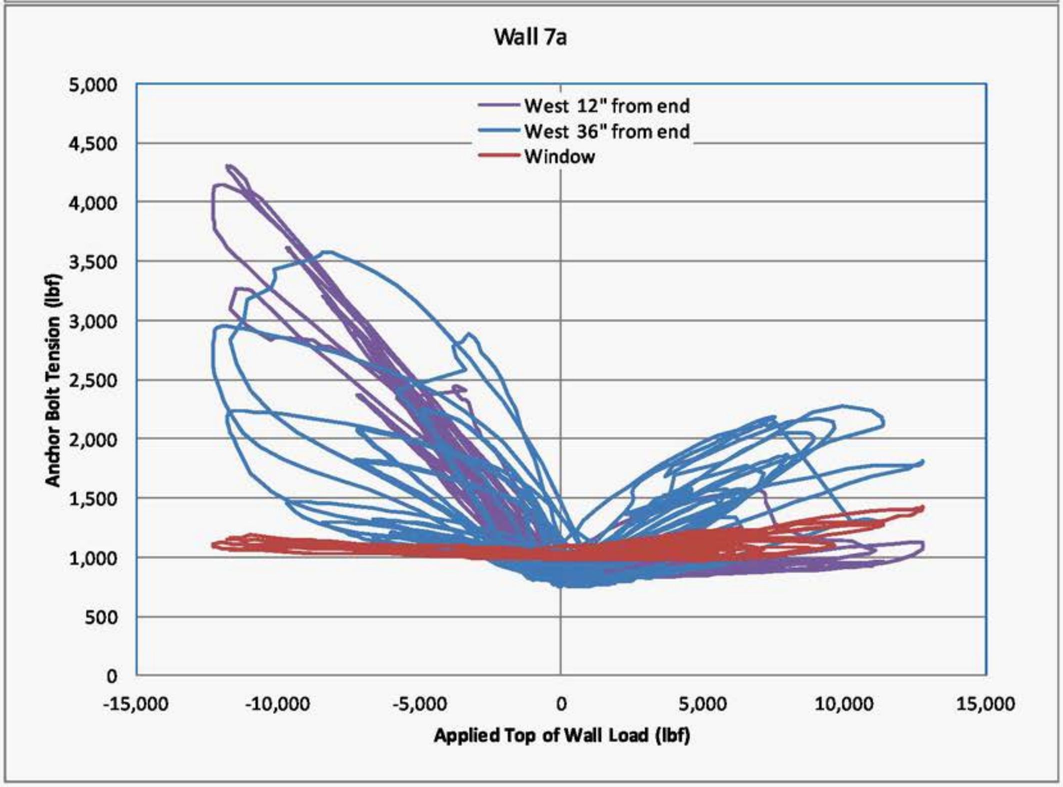

Wall 5b
Pier
Window
6,000
5,000
4,000
3,000
2,000
1,000
0
-1,000
-2,000
Anchor Bolt Tension (lbf)
-15,000
-10,000
-5,000
0
5,000
10,000
15,000
Applied Top of Wall Load (lbf)

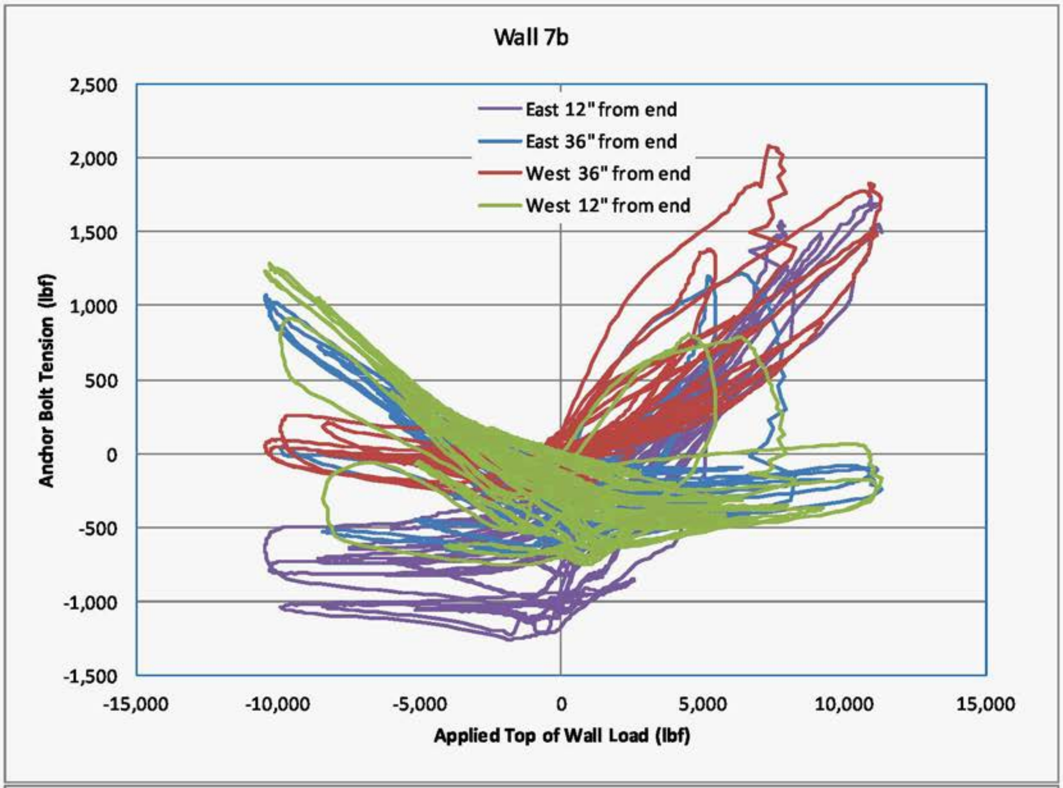

Wall 5c
Pier
Window
1,000
800
600
400
200
0
-200
-400
-600
Anchor Bolt Tension (lbf)
0
3,000
6,000
9,000
12,000
15,000
Applied Top of Wall Load (lbf)

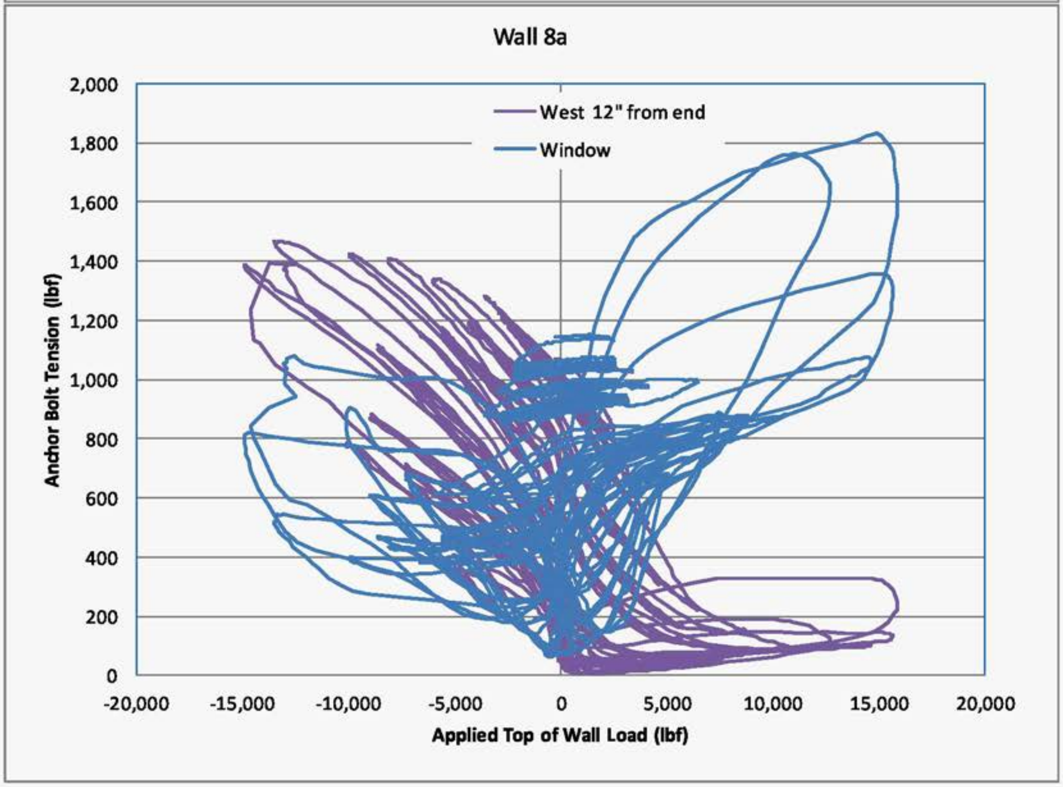

Wall 5d
Pier
Window
Anchor Bolt Tension (lbf)
Applied Top of Wall Load (lbf)
3,000
2,500
2,000
1,500
1,000
500
0
-15,000
-10,000
-5,000
0
5,000
10,000
15,000

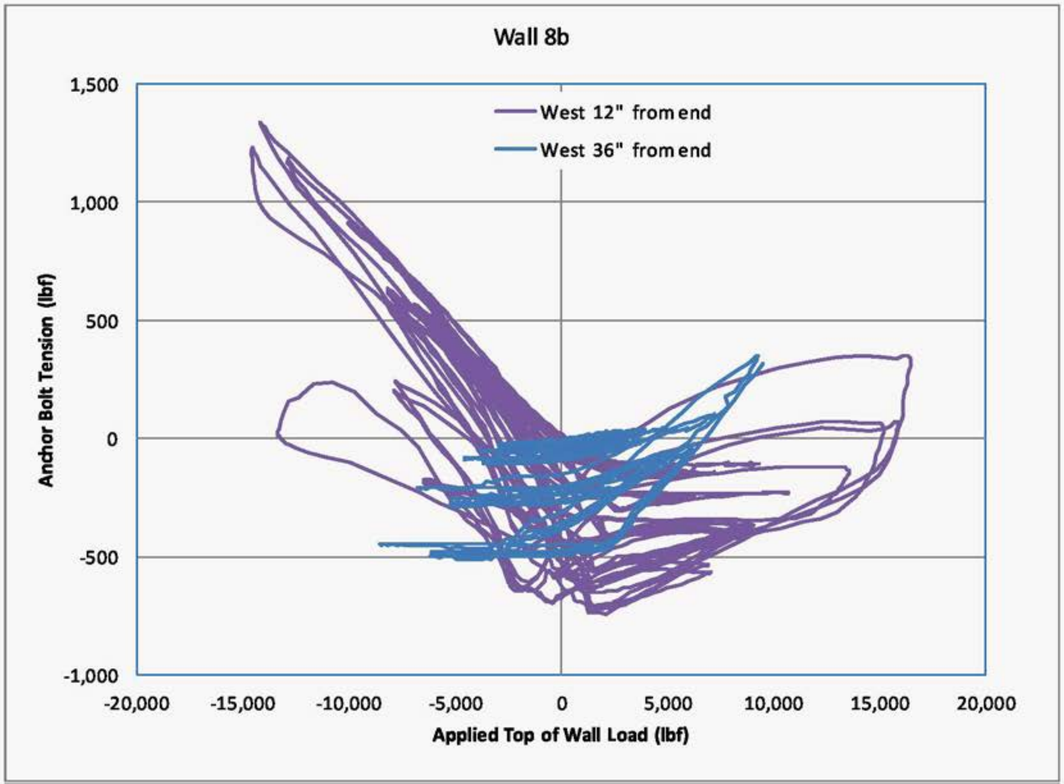

Wall 6a
Pier
Window
Anchor Bolt Tension (lbf)
Applied Top of Wall Load (lbf)
2,500
2,000
1,500
1,000
500
0
-500
-1,000
-15,000
-10,000
-5,000
0
5,000
10,000
15,000

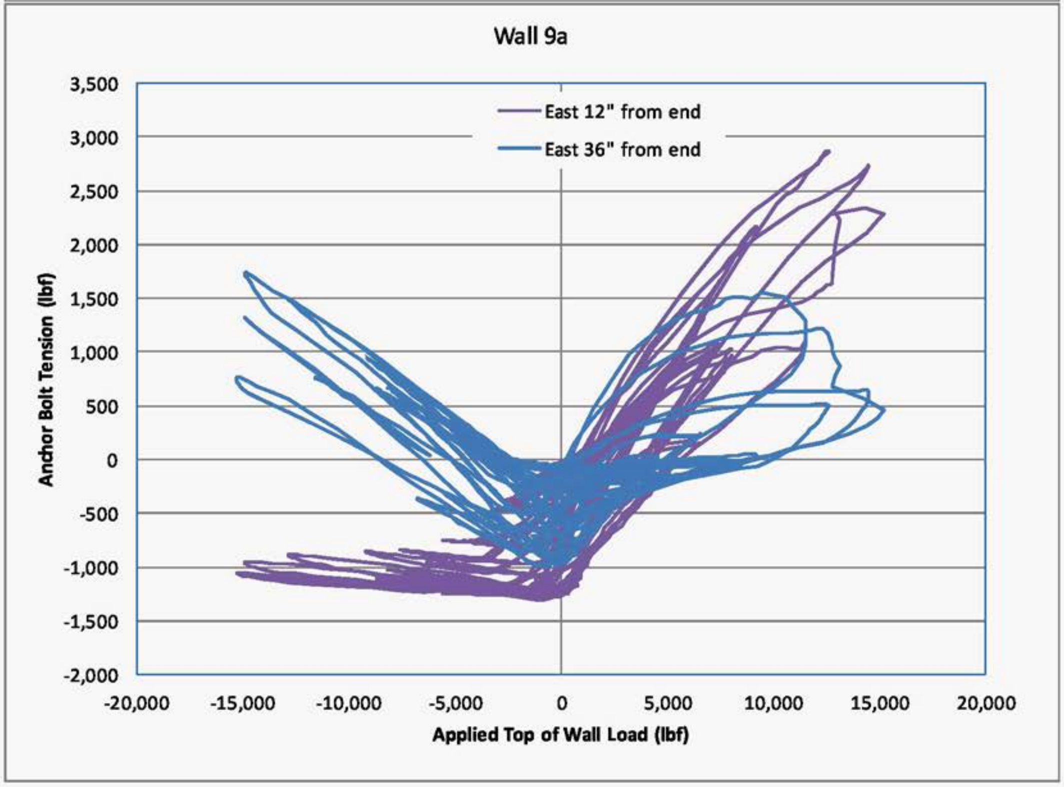

Wall 6b
East Pier
West Pier
Anchor Bolt Tension (lbf)
2,000
1,500
1,000
500
0
-500
-1,000
-15,000
-10,000
-5,000
0
5,000
10,000
15,000
Applied Top of Wall Load (lbf)

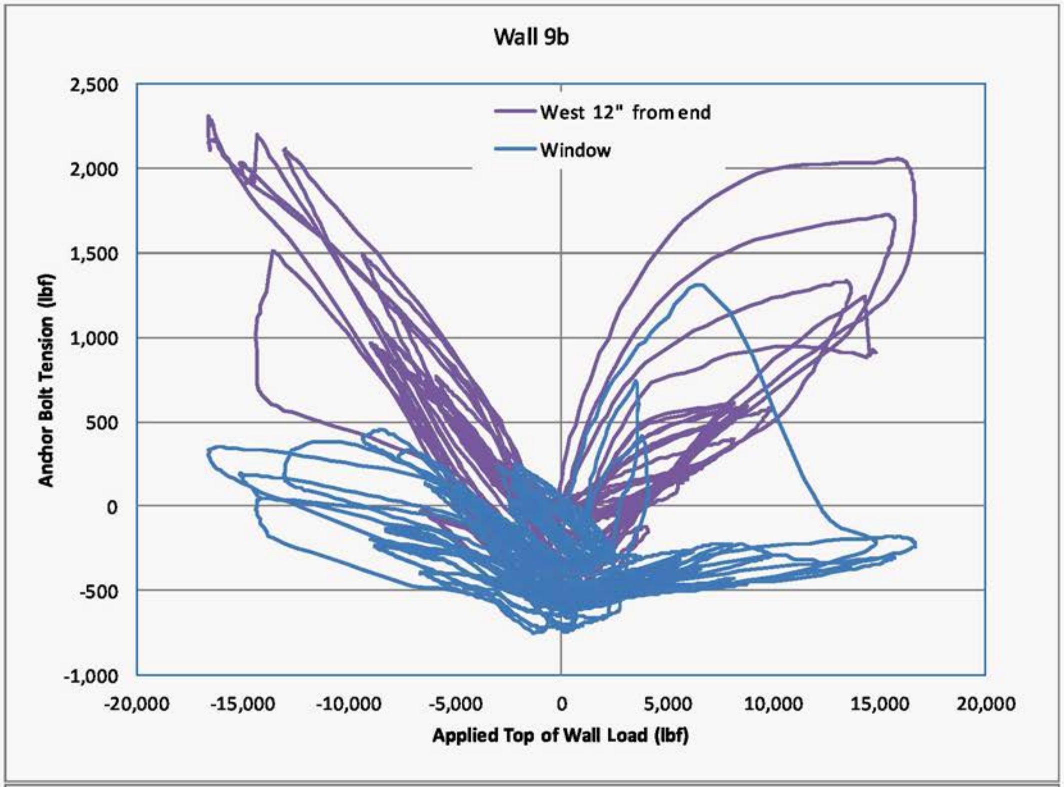

Wall 7a
West 12" from end
West 36" from end
Window
Anchor Bolt Tension (lbf)
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
-15,000
-10,000
-5,000
0
5,000
10,000
15,000
Applied Top of Wall Load (lbf)

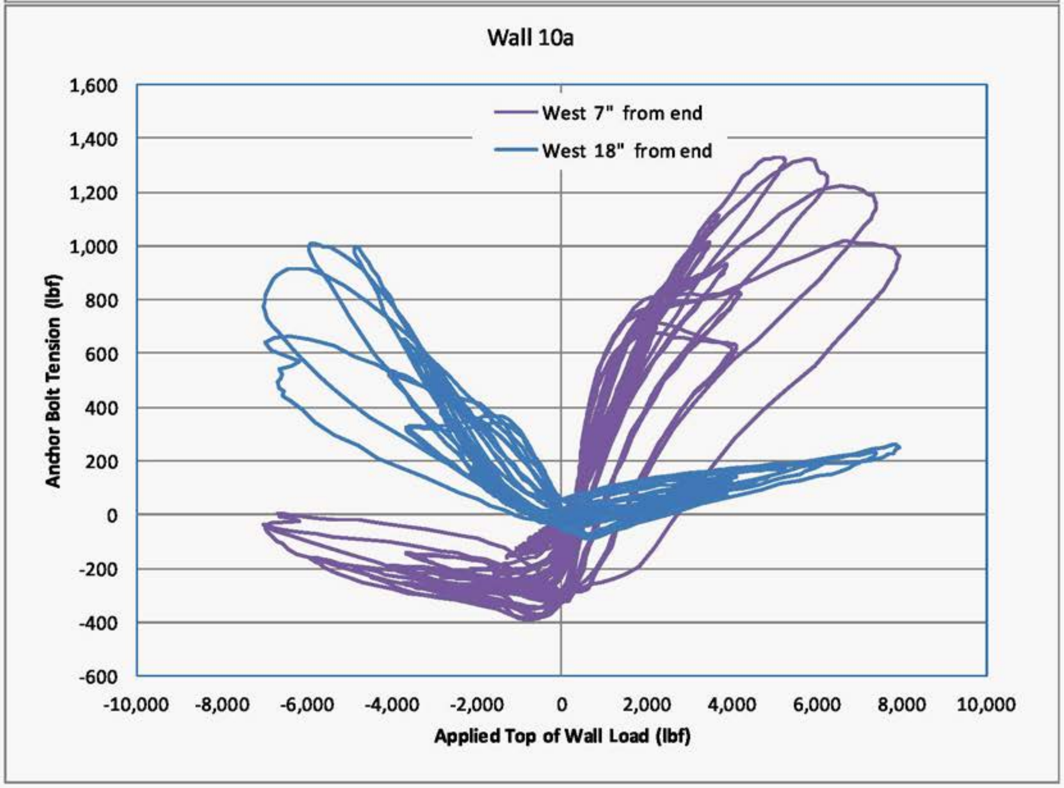

Wall 7b
East 12" from end
East 36" from end
West 36" from end
West 12" from end
Anchor Bolt Tension (lbf)
2,500
2,000
1,500
1,000
500
0
-500
-1,000
-1,500
-15,000
-10,000
-5,000
0
5,000
10,000
15,000
Applied Top of Wall Load (lbf)

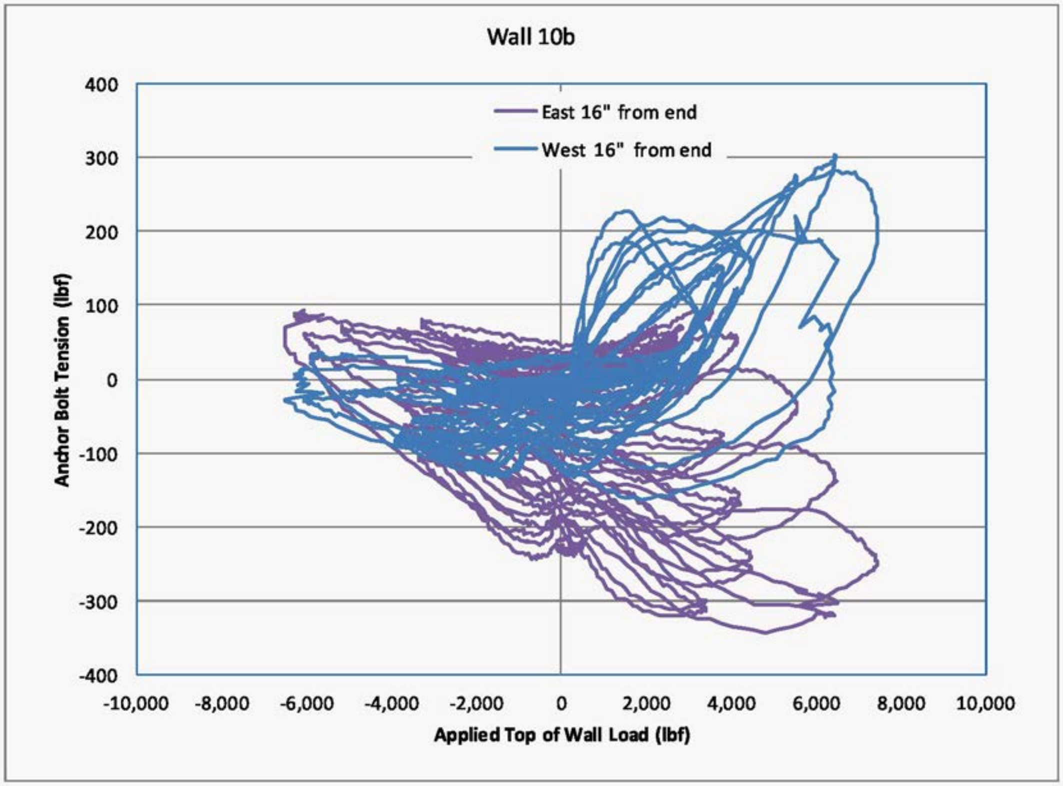

Wall 8a
West 12" from end
Window
Anchor Bolt Tension (lbf)
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
-20,000
-15,000
-10,000
-5,000
0
5,000
10,000
15,000
20,000
Applied Top of Wall Load (lbf)


Wall 8b
West 12" from end
West 36" from end
Anchor Bolt Tension (lbf)
1,500
1,000
500
0
-500
-1,000
-20,000
-15,000
-10,000
-5,000
0
5,000
10,000
15,000
20,000
Applied Top of Wall Load (lbf)

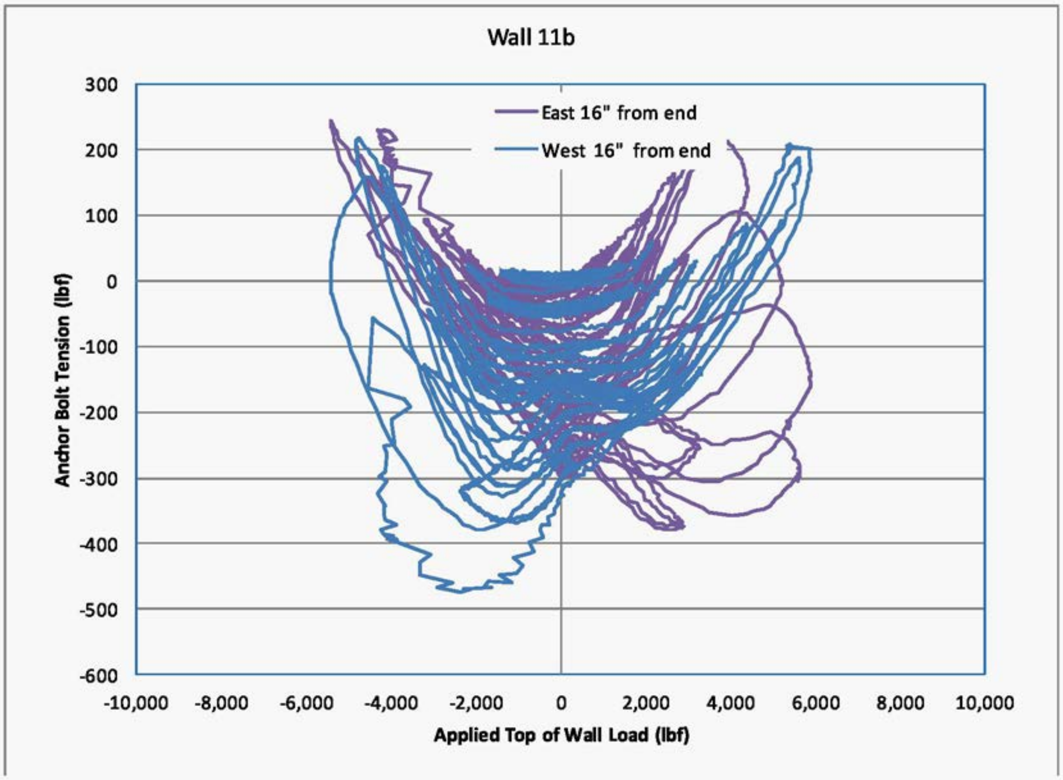

Wall 9a
East 12" from end
East 36" from end
Anchor Bolt Tension (lbf)
3,500
3,000
2,500
2,000
1,500
1,000
500
0
-500
-1,000
-1,500
-2,000
-20,000
-15,000
-10,000
-5,000
0
5,000
10,000
15,000
20,000
Applied Top of Wall Load (lbf)


Wall 9b
West 12" from end
Window
Anchor Bolt Tension (lbf)
2,500
2,000
1,500
1,000
500
0
-500
-1,000
-20,000
-15,000
-10,000
-5,000
0
5,000
10,000
15,000
20,000
Applied Top of Wall Load (lbf)

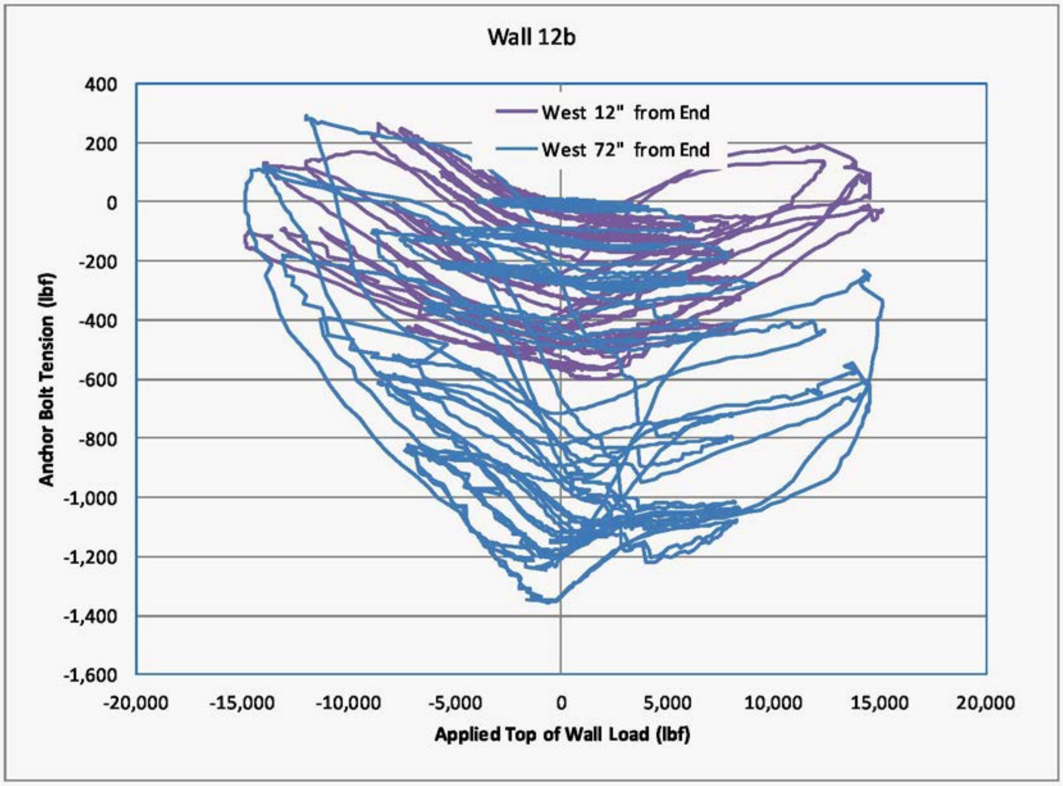

Wall 10a
West 7" from end
West 18" from end
Anchor Bolt Tension (lbf)
1,600
1,400
1,200
1,000
800
600
400
200
0
-200
-400
-600
-10,000
-8,000
-6,000
-4,000
-2,000
0
2,000
4,000
6,000
8,000
10,000
Applied Top of Wall Load (lbf)



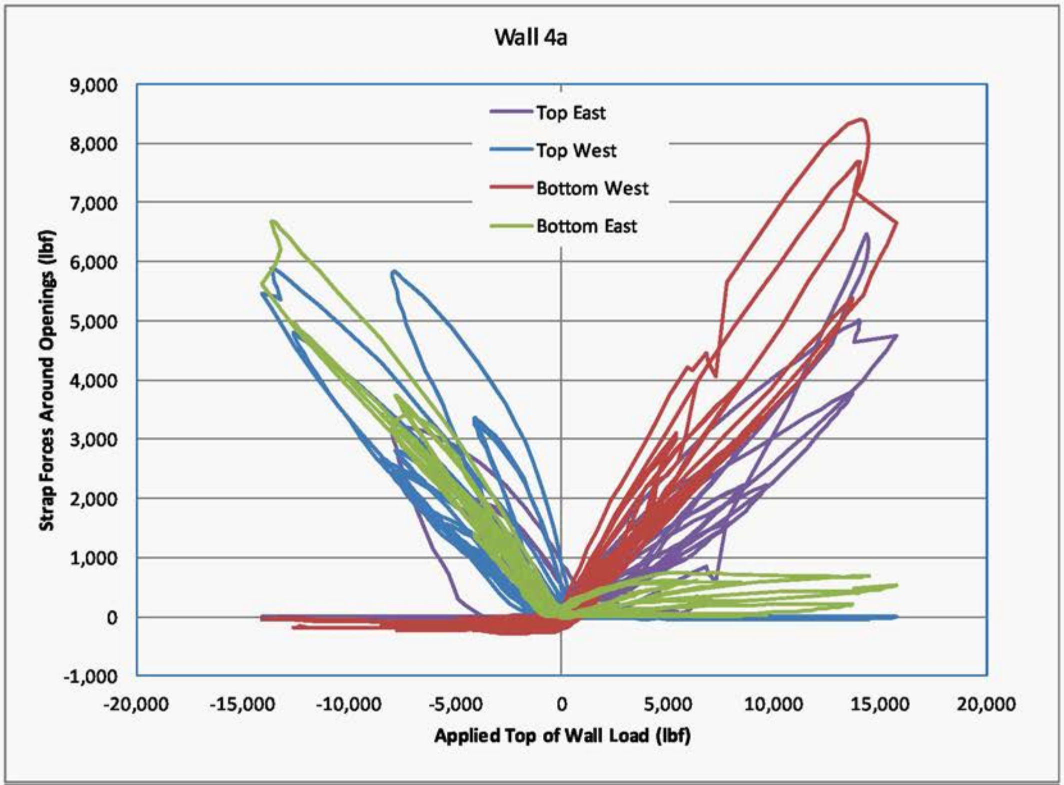
No anchor bolt data collected for Wall 11a

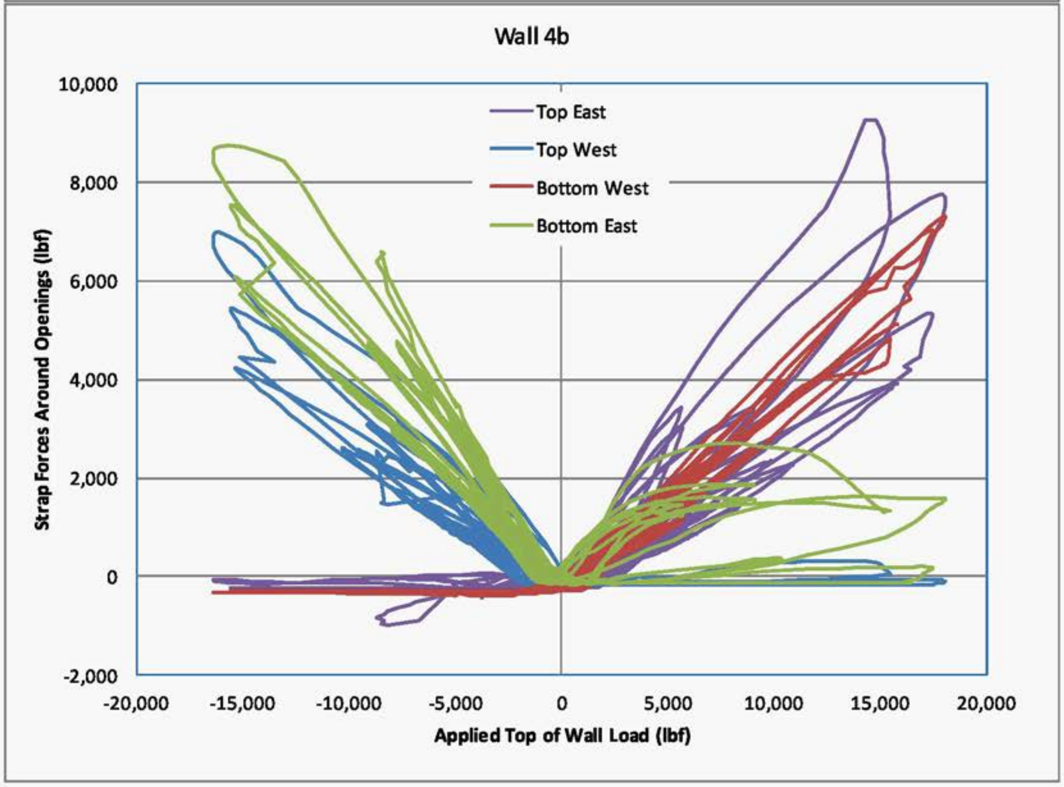


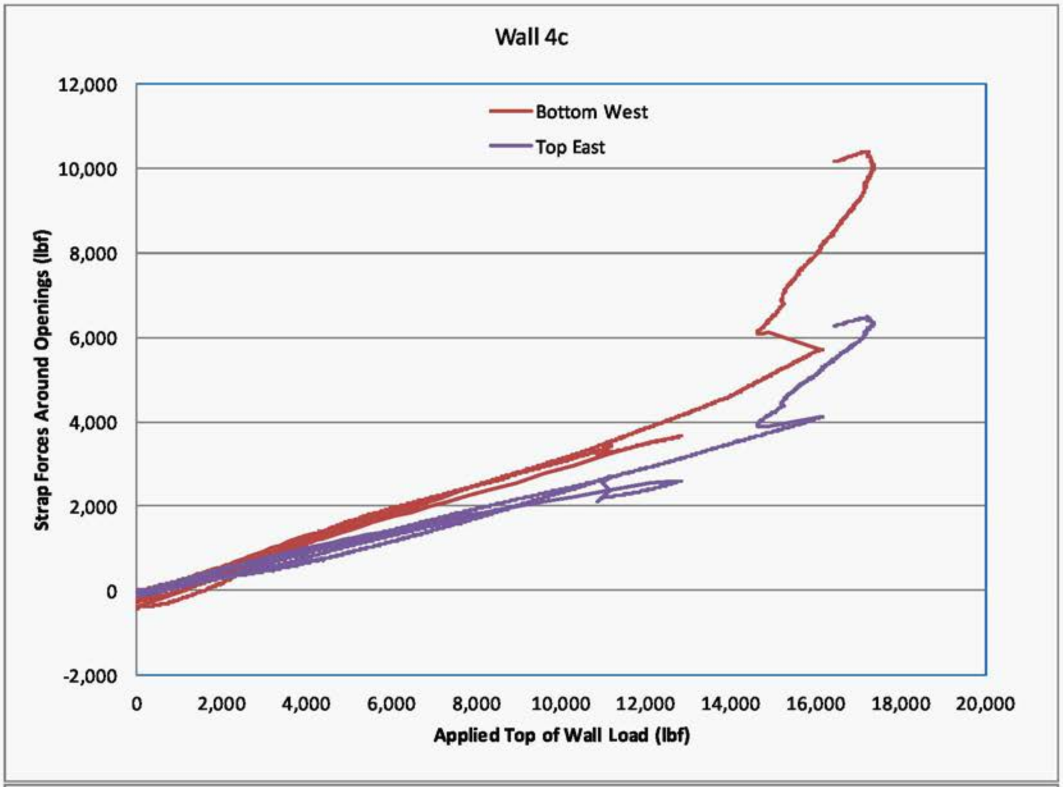
No anchor bolt data collected for Wall 12a

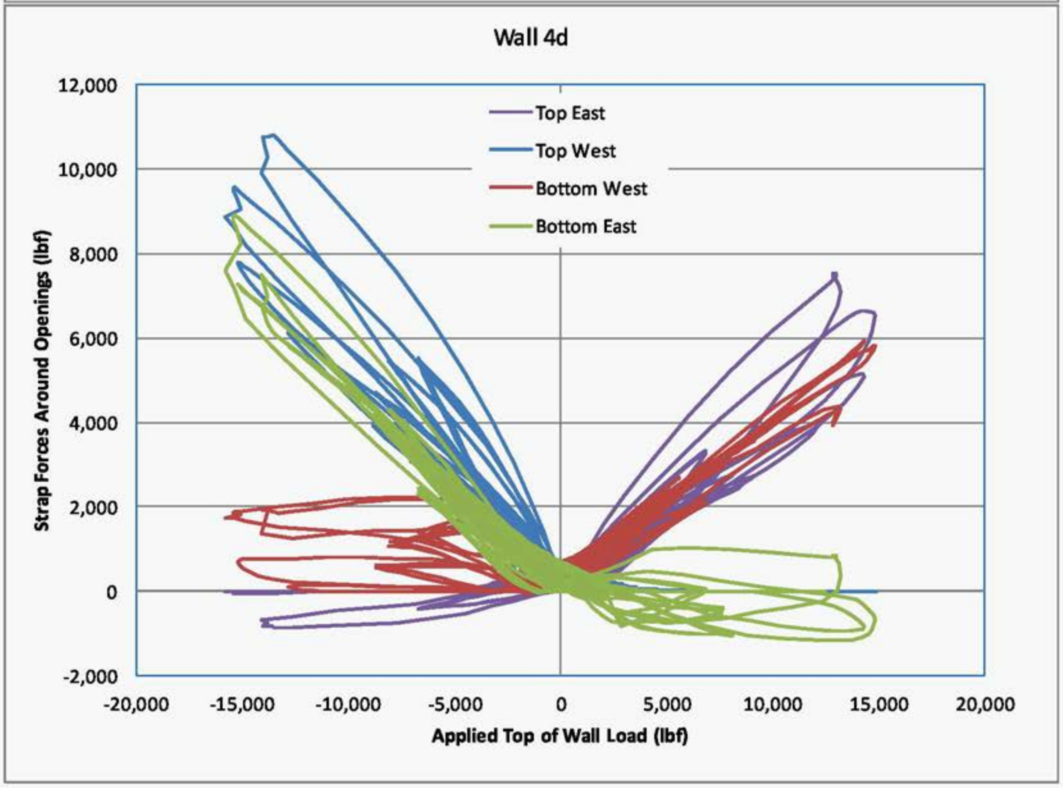

Wall 12b
West 12" from End
West 72" from End
Anchor Bolt Tension (lbf)
400
200
0
-200
-400
-600
-800
-1,000
-1,200
-1,400
-1,600
-20,000
-15,000
-10,000
-5,000
0
5,000
10,000
15,000
20,000
Applied Top of Wall Load (lbf)

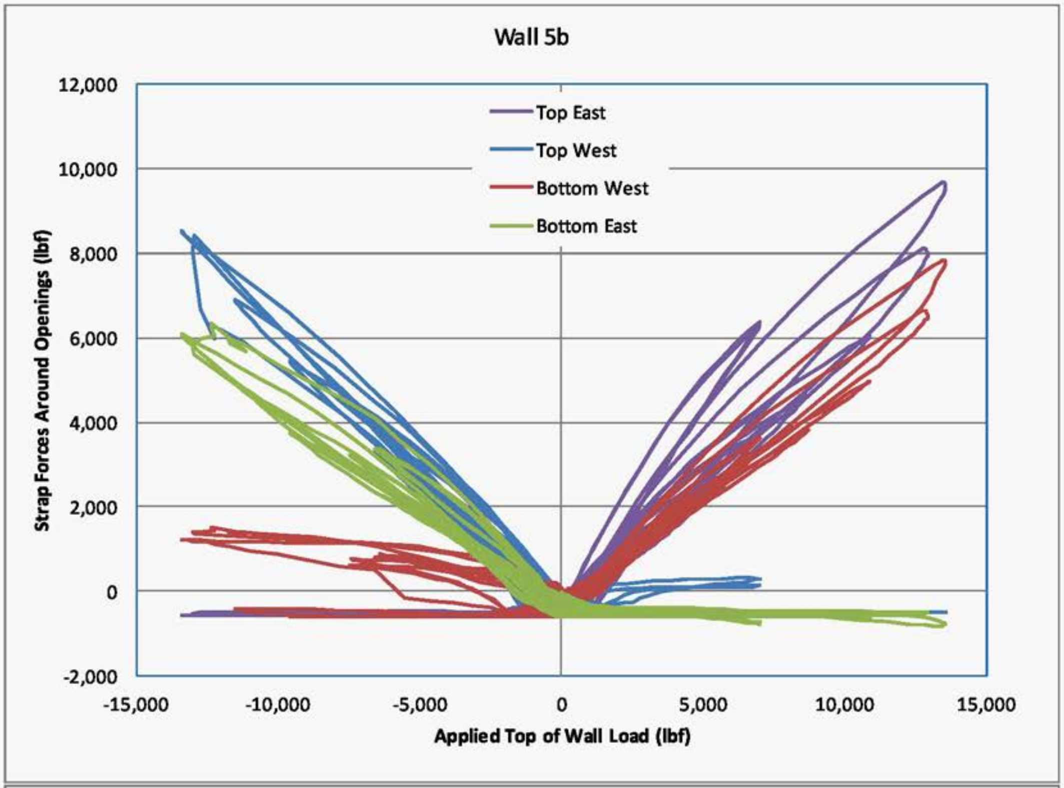
APPENDIX E – STRAP FORCES AROUND OPENINGS

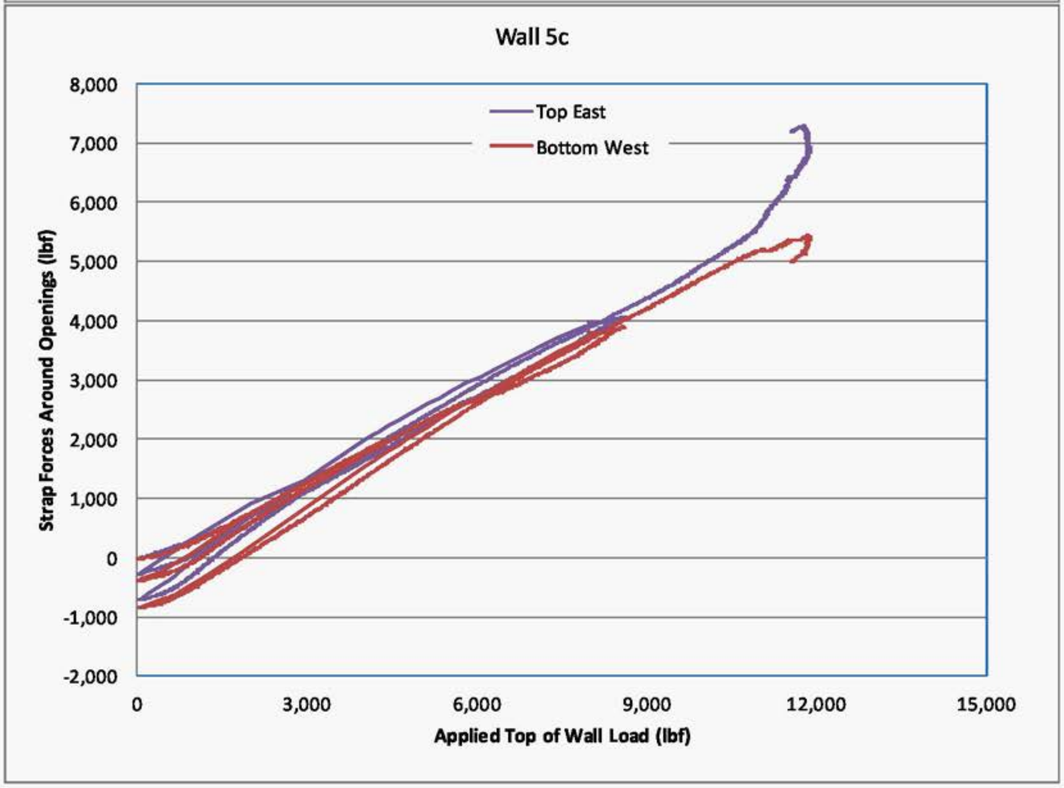


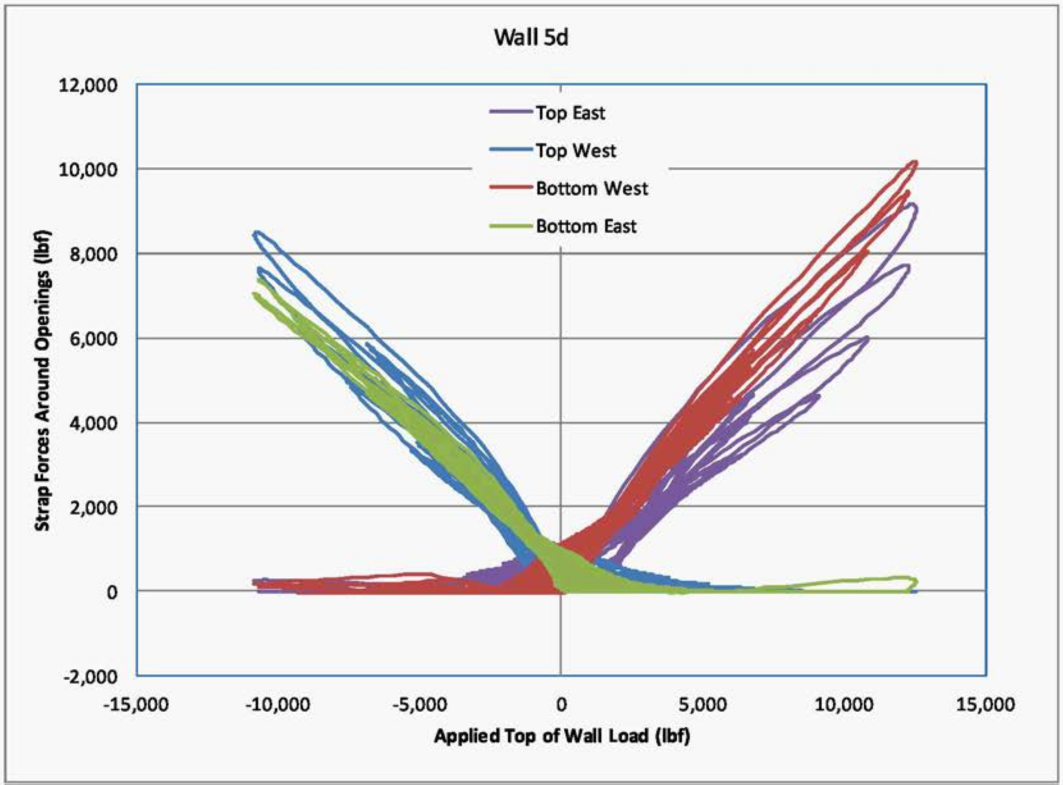


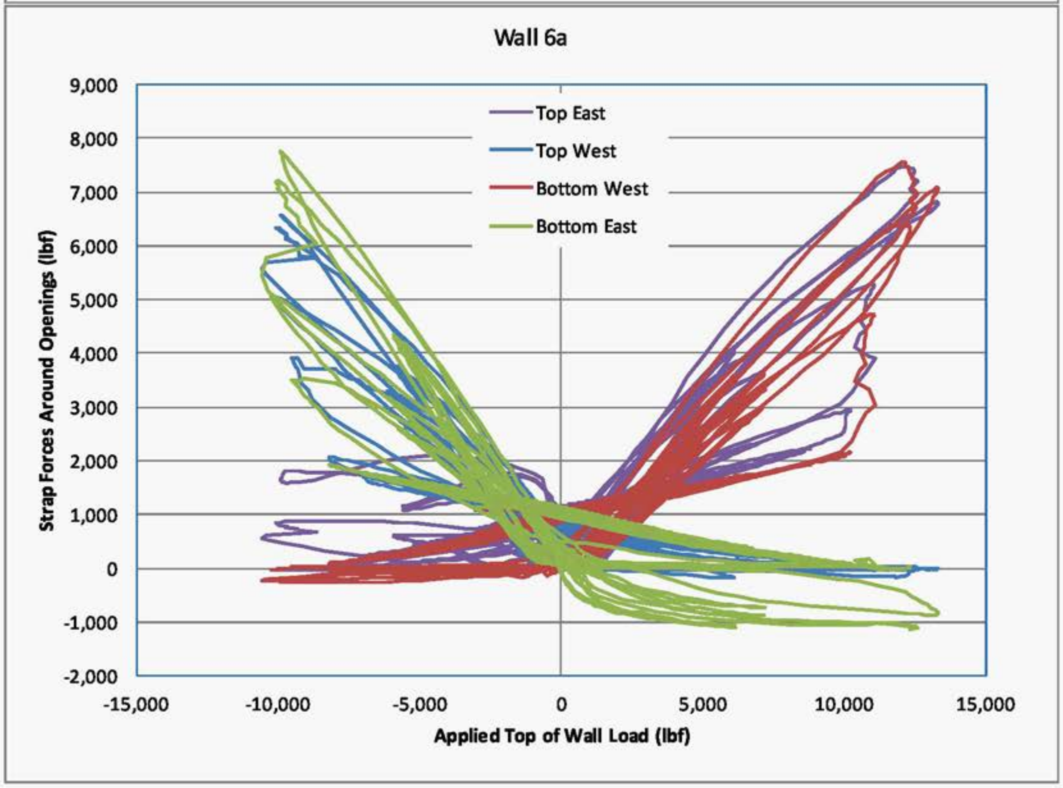

Wall 4c
Bottom West
Top East
Strap Forces Around Openings (lbf)
12,000
10,000
8,000
6,000
4,000
2,000
0
-2,000
0
2,000
4,000
6,000
8,000
10,000
12,000
14,000
16,000
18,000
20,000
Applied Top of Wall Load (lbf)

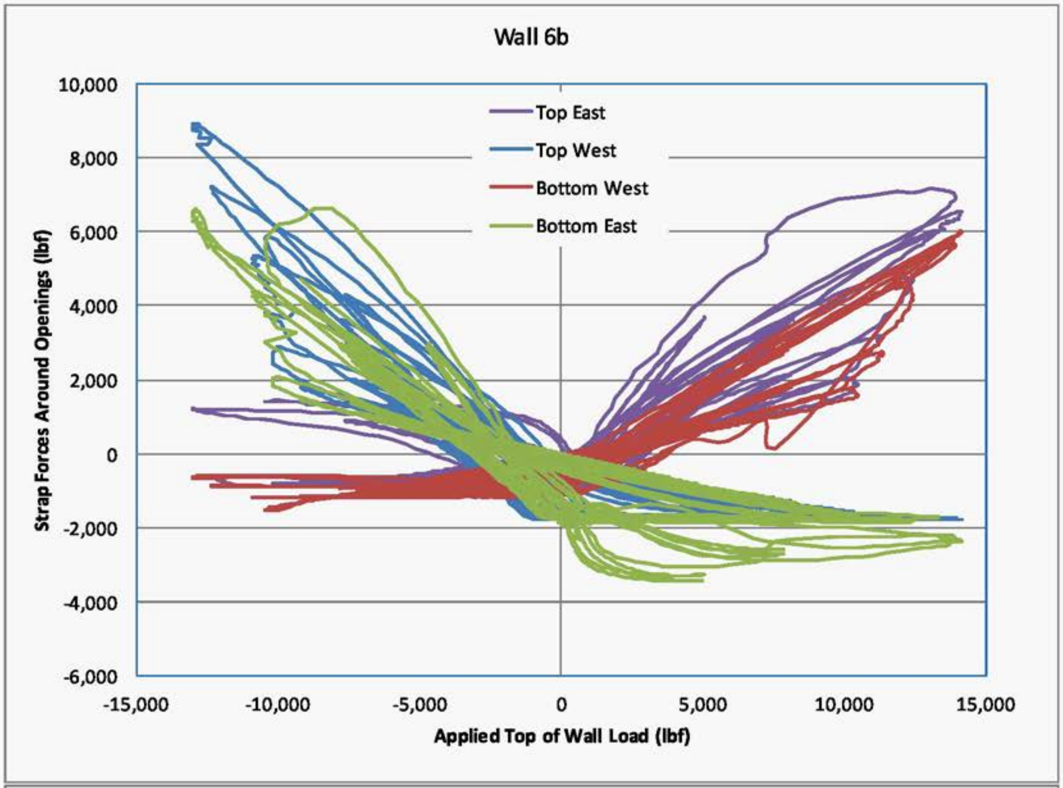

Wall 4d
Top East
Top West
Bottom West
Bottom East
Strap Forces Around Openings (lbf)
12,000
10,000
8,000
6,000
4,000
2,000
0
-2,000
-20,000
-15,000
-10,000
-5,000
0
5,000
10,000
15,000
20,000
Applied Top of Wall Load (lbf)

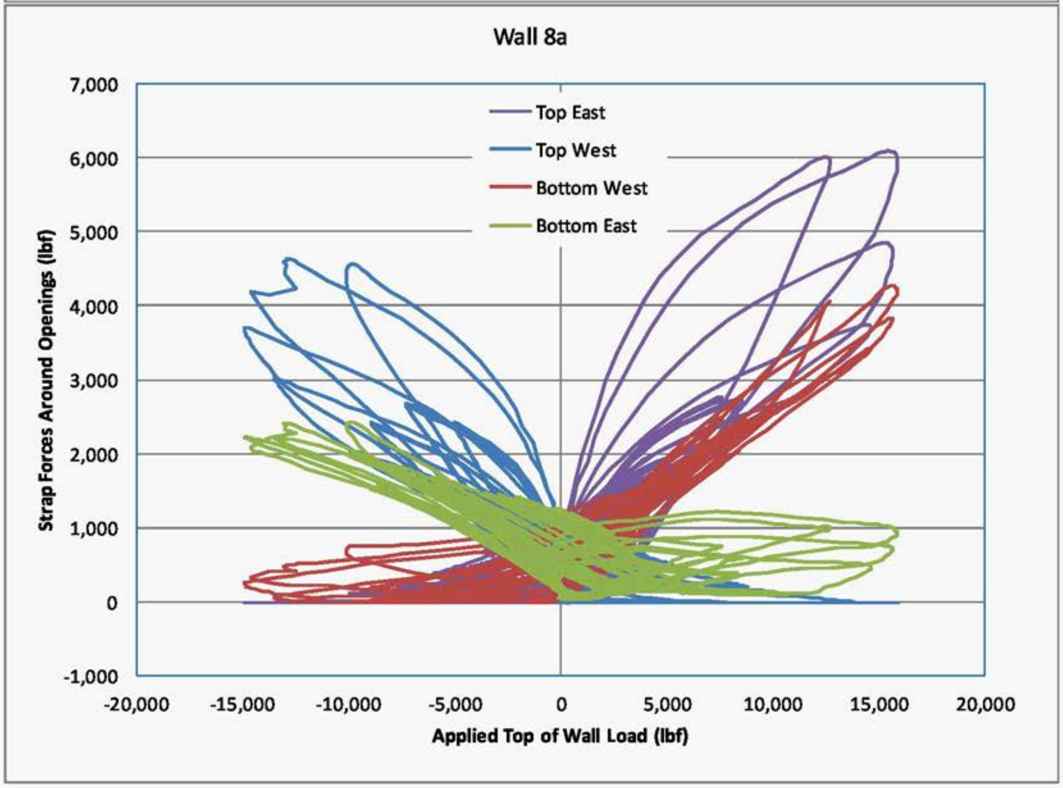

Wall 5b
Top East
Top West
Bottom West
Bottom East
Strap Forces Around Openings (lbf)
12,000
10,000
8,000
6,000
4,000
2,000
0
-2,000
-15,000
-10,000
-5,000
0
5,000
10,000
15,000
Applied Top of Wall Load (lbf)

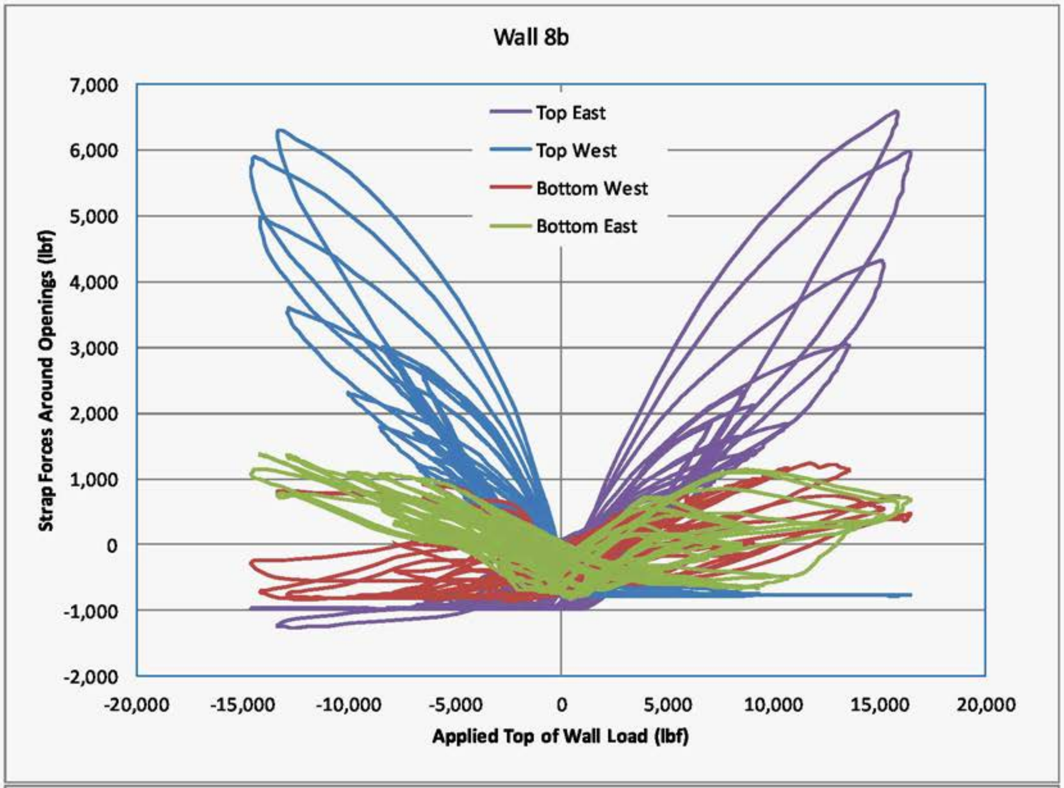

Wall 5c
Top East
Bottom West
Strap Forces Around Openings (lbf)
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
-1,000
-2,000
0
3,000
6,000
9,000
12,000
15,000
Applied Top of Wall Load (lbf)

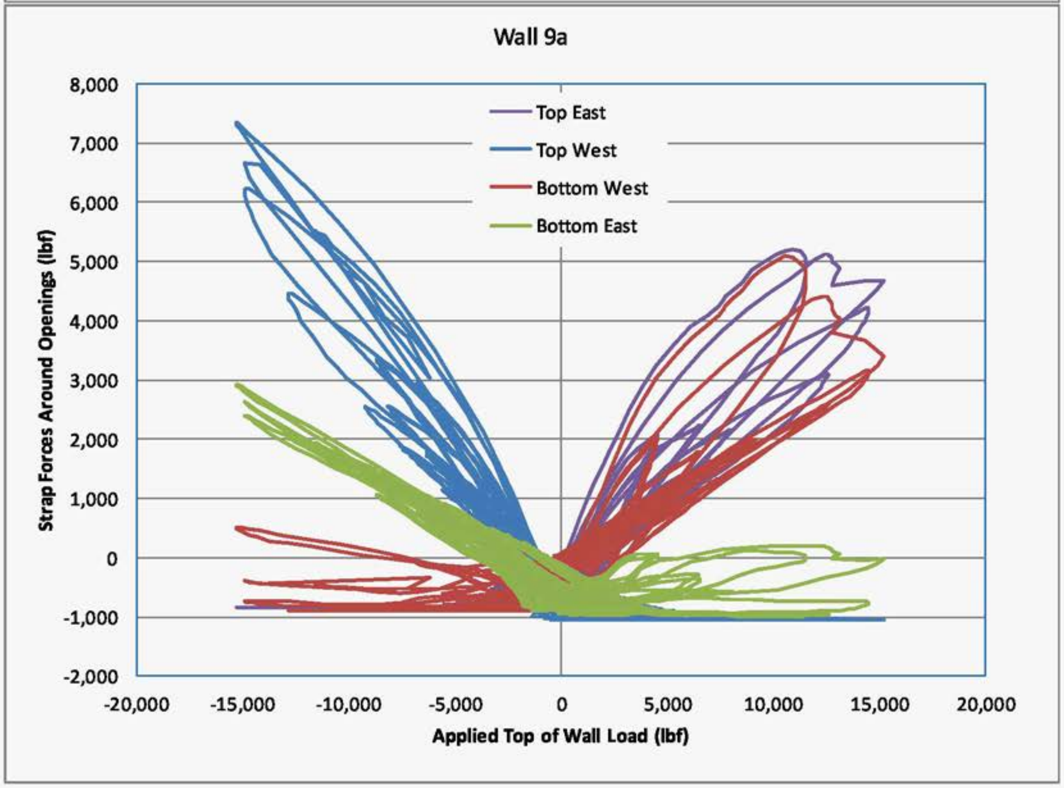

Wall 5d
Top East
Top West
Bottom West
Bottom East
Strap Forces Around Openings (lbf)
Applied Top of Wall Load (lbf)
12,000
10,000
8,000
6,000
4,000
2,000
0
-2,000
-15,000
-10,000
-5,000
0
5,000
10,000
15,000

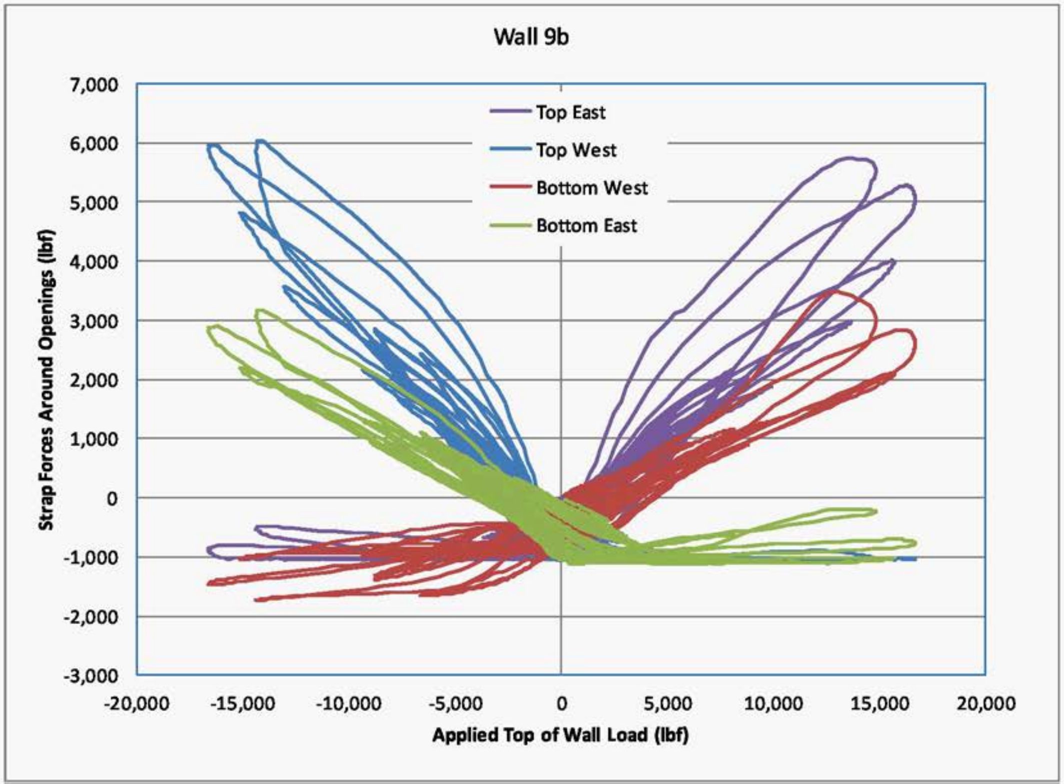

Wall 6a
Top East
Top West
Bottom West
Bottom East
Strap Forces Around Openings (lbf)
Applied Top of Wall Load (lbf)
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
-1,000
-2,000
-15,000
-10,000
-5,000
0
5,000
10,000
15,000

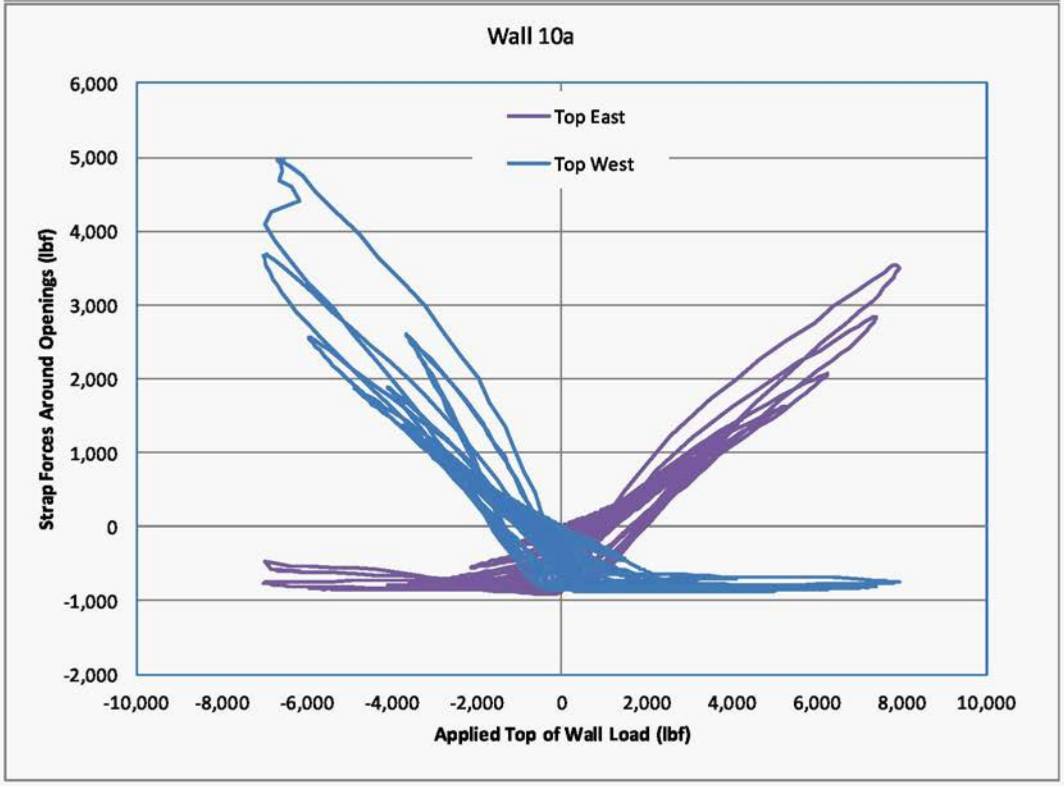

Wall 6b
Top East
Top West
Bottom West
Bottom East
Strap Forces Around Openings (lbf)
Applied Top of Wall Load (lbf)
10,000
8,000
6,000
4,000
2,000
0
-2,000
-4,000
-6,000
-15,000
-10,000
-5,000
0
5,000
10,000
15,000

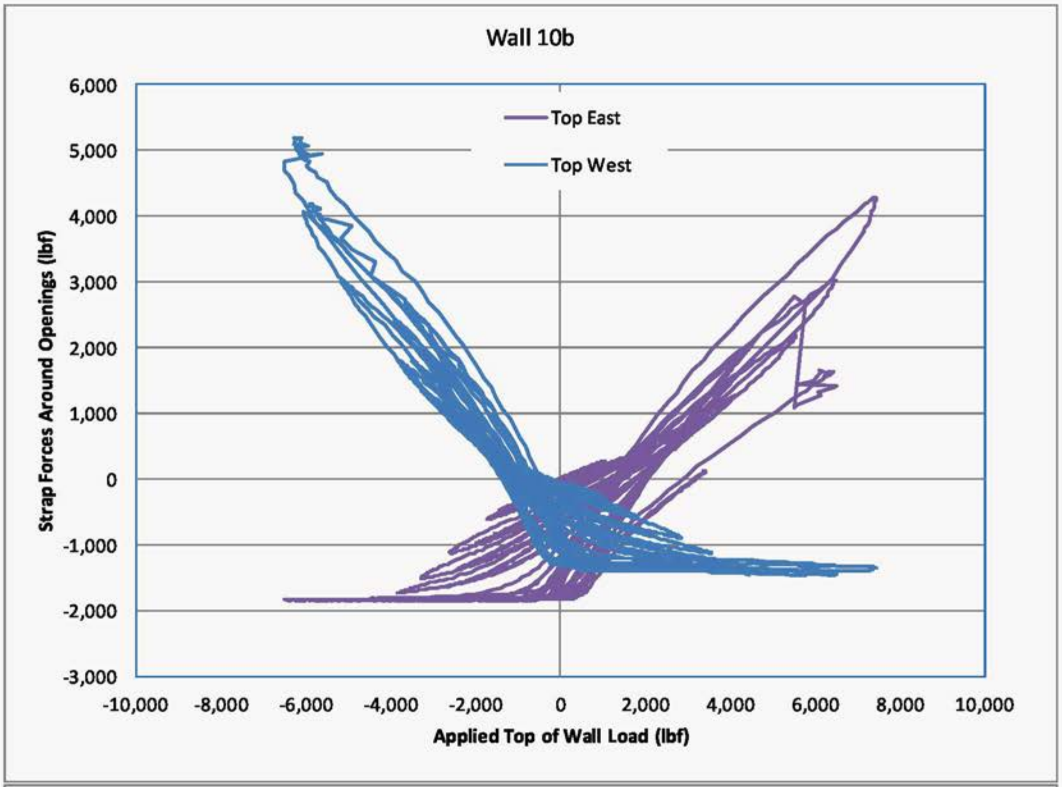

Wall 8a
Top East
Top West
Bottom West
Bottom East
Strap Forces Around Openings (lbf)
Applied Top of Wall Load (lbf)
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
-1,000
-20,000
-15,000
-10,000
-5,000
0
5,000
10,000
15,000
20,000

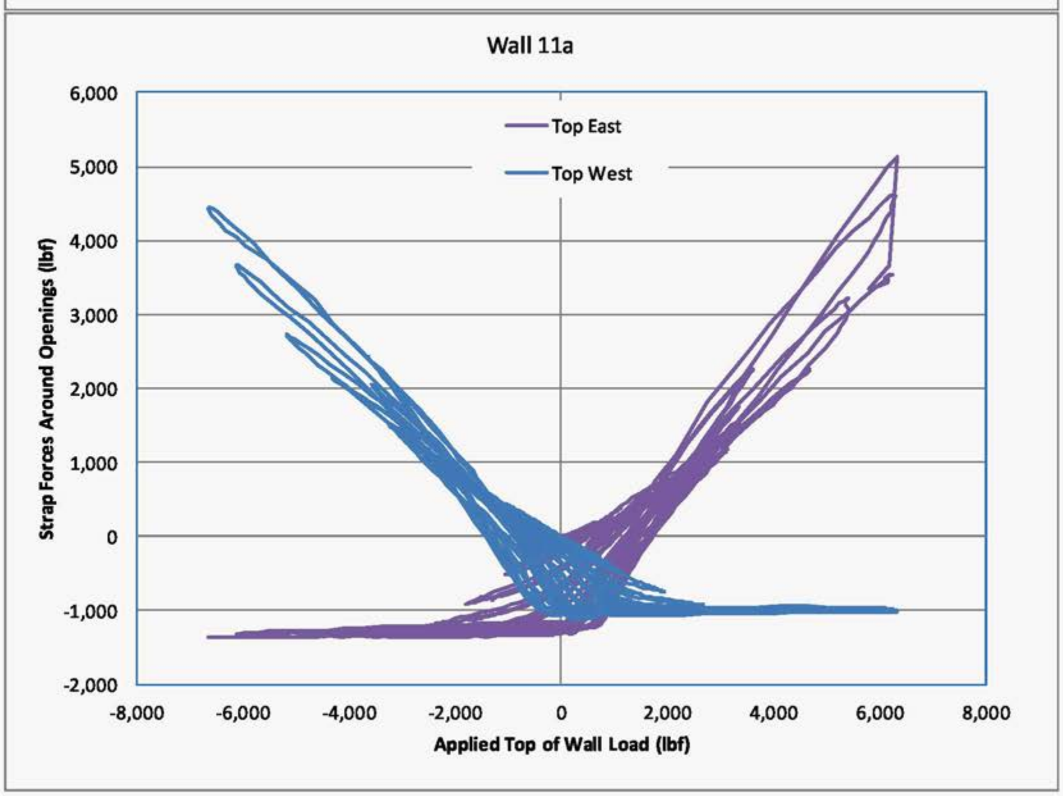

Wall 8b
Top East
Top West
Bottom West
Bottom East
Strap Forces Around Openings (lbf)
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
-1,000
-2,000
-20,000
-15,000
-10,000
-5,000
0
5,000
10,000
15,000
20,000
Applied Top of Wall Load (lbf)

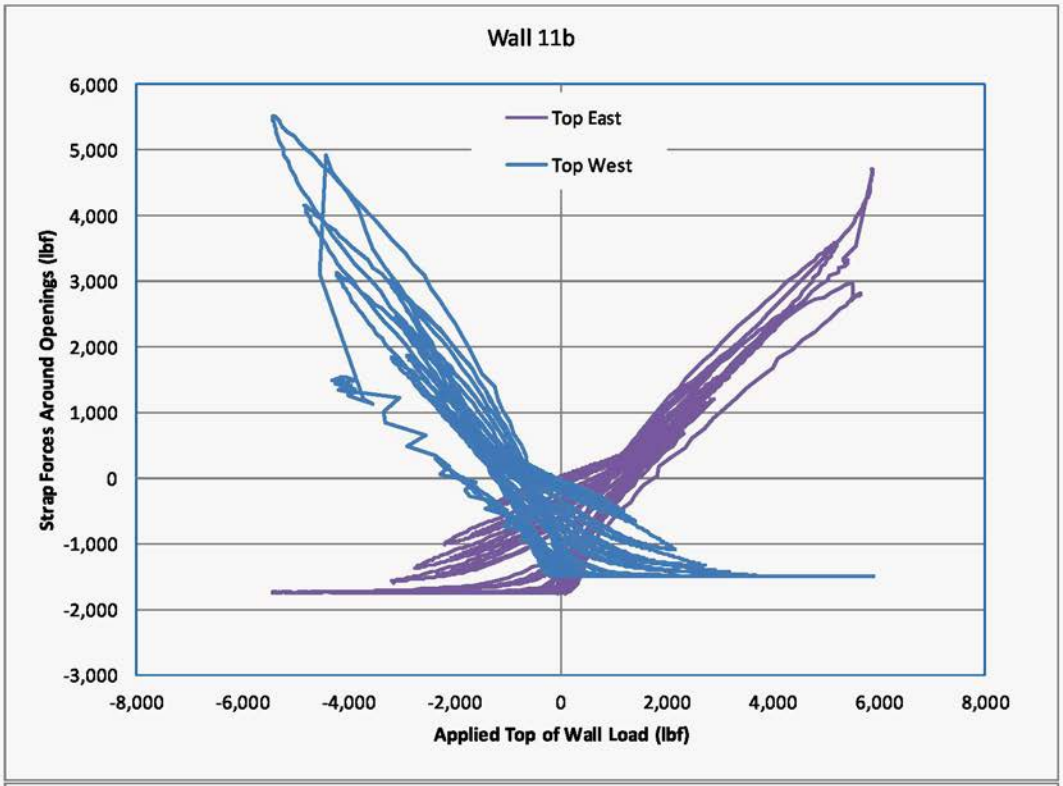

Wall 9a
Top East
Top West
Bottom West
Bottom East
Strap Forces Around Openings (lbf)
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
-1,000
-2,000
-20,000
-15,000
-10,000
-5,000
0
5,000
10,000
15,000
20,000
Applied Top of Wall Load (lbf)

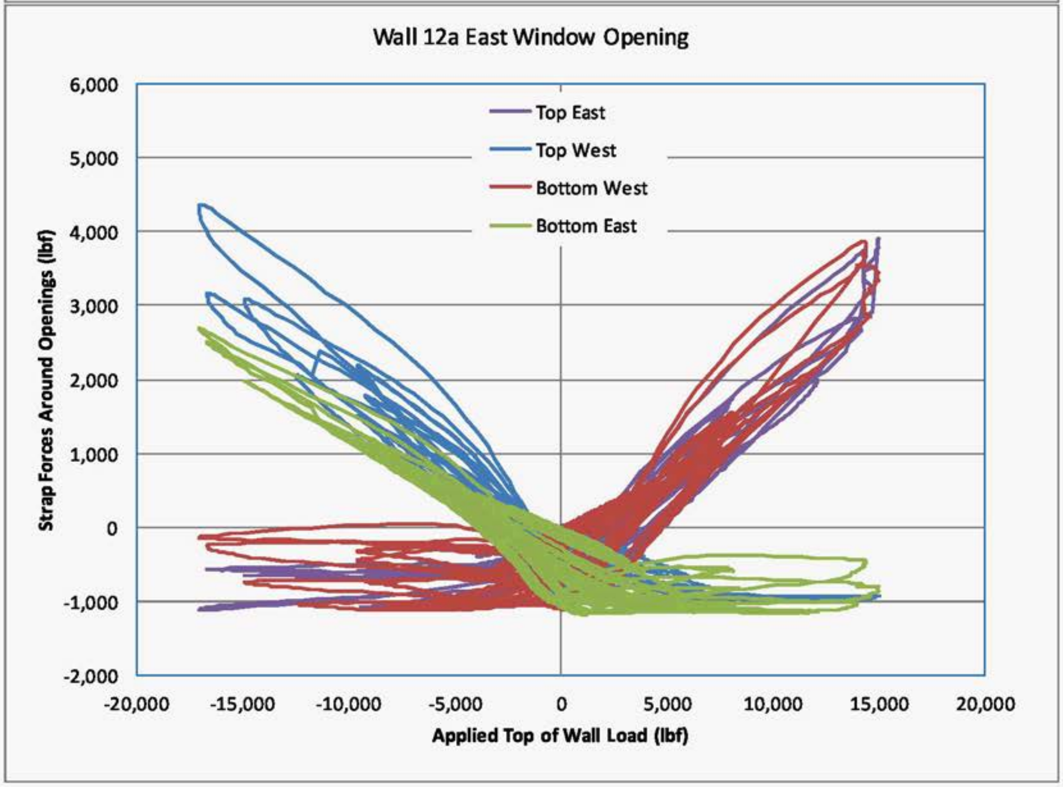

Wall 9b
Top East
Top West
Bottom West
Bottom East
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
-1,000
-2,000
-3,000
Strap Forces Around Openings (lbf)
-20,000
-15,000
-10,000
-5,000
0
5,000
10,000
15,000
20,000
Applied Top of Wall Load (lbf)


Wall 10a
Top East
Top West
6,000
5,000
4,000
3,000
2,000
1,000
0
-1,000
-2,000
Strap Forces Around Openings (lbf)
-10,000
-8,000
-6,000
-4,000
-2,000
0
2,000
4,000
6,000
8,000
10,000
Applied Top of Wall Load (lbf)

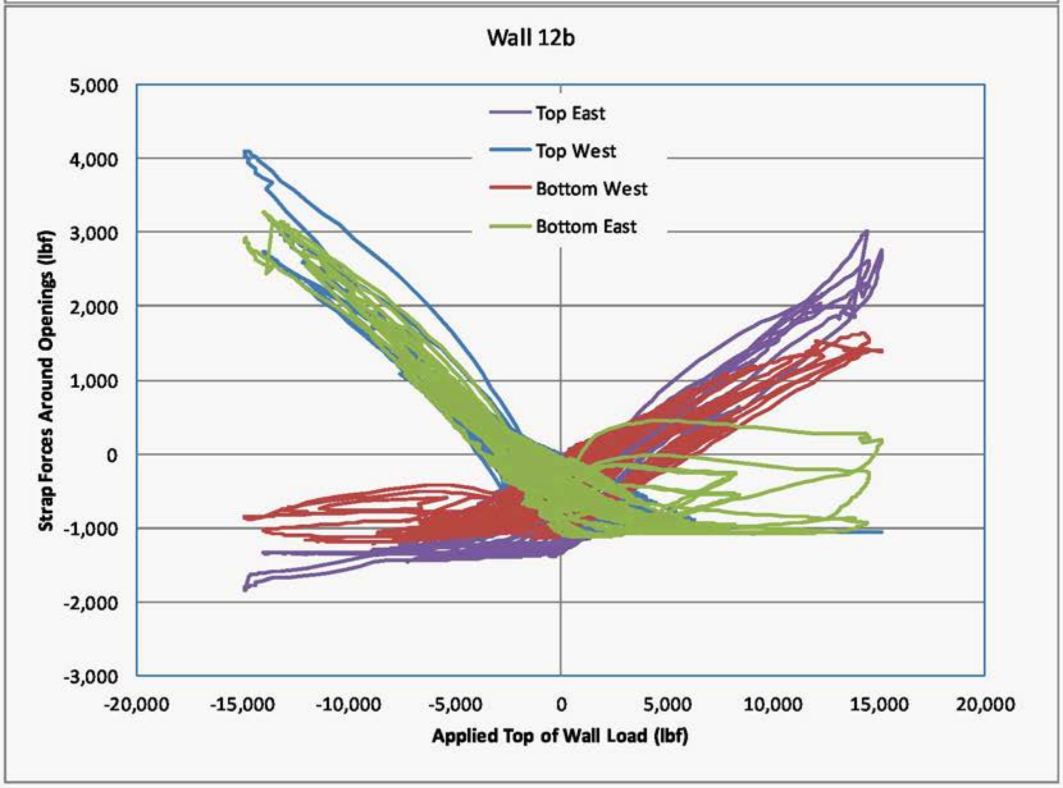

Wall 10b
Top East
Top West
Strap Forces Around Openings (lbf)
6,000
5,000
4,000
3,000
2,000
1,000
0
-1,000
-2,000
-3,000
-10,000
-8,000
-6,000
-4,000
-2,000
0
2,000
4,000
6,000
8,000
10,000
Applied Top of Wall Load (lbf)


Wall 11a
Top East
Top West
Strap Forces Around Openings (lbf)
6,000
5,000
4,000
3,000
2,000
1,000
0
-1,000
-2,000
-8,000
-6,000
-4,000
-2,000
0
2,000
4,000
6,000
8,000
Applied Top of Wall Load (lbf)


Wall 11b
Top East
Top West
Strap Forces Around Openings (lbf)
Applied Top of Wall Load (lbf)
6,000
5,000
4,000
3,000
2,000
1,000
0
-1,000
-2,000
-3,000
-8,000
-6,000
-4,000
-2,000
0
2,000
4,000
6,000
8,000


Wall 12a East Window Opening
Top East
Top West
Bottom West
Bottom East
Strap Forces Around Openings (lbf)
Applied Top of Wall Load (lbf)
6,000
5,000
4,000
3,000
2,000
1,000
0
-1,000
-2,000
-20,000
-15,000
-10,000
-5,000
0
5,000
10,000
15,000
20,000


Wall 12a West Window Opening
Top West
Bottom West
Strap Forces Around Openings (lbf)
6,000
5,000
4,000
3,000
2,000
1,000
0
-1,000
-2,000
-20,000
-15,000
-10,000
-5,000
0
5,000
10,000
15,000
20,000
Applied Top of Wall Load (lbf)


Wall 12b
Top East
Top West
Bottom West
Bottom East
Strap Forces Around Openings (lbf)
5,000
4,000
3,000
2,000
1,000
0
-1,000
-2,000
-3,000
-20,000
-15,000
-10,000
-5,000
0
5,000
10,000
15,000
20,000
Applied Top of Wall Load (lbf)

APPENDIX F - PHOTOS

FIGURE F1

DOUBLE TOP PLATE FAILURE FOR WALL 4A, USING "SHORT" LOAD HEAD)

FIGURE F2

WALL 5A, WITH "INTERMEDIATE' LOAD HEAD (PAINTED GRAY

FIGURE F3

WALL 7B, WITH "LONG" LOAD HEAD (unpainted steel)

FIGURE F4

WALL 5C, WITH NO LOAD HEAD (Actuator is pushing directly on double top plate)

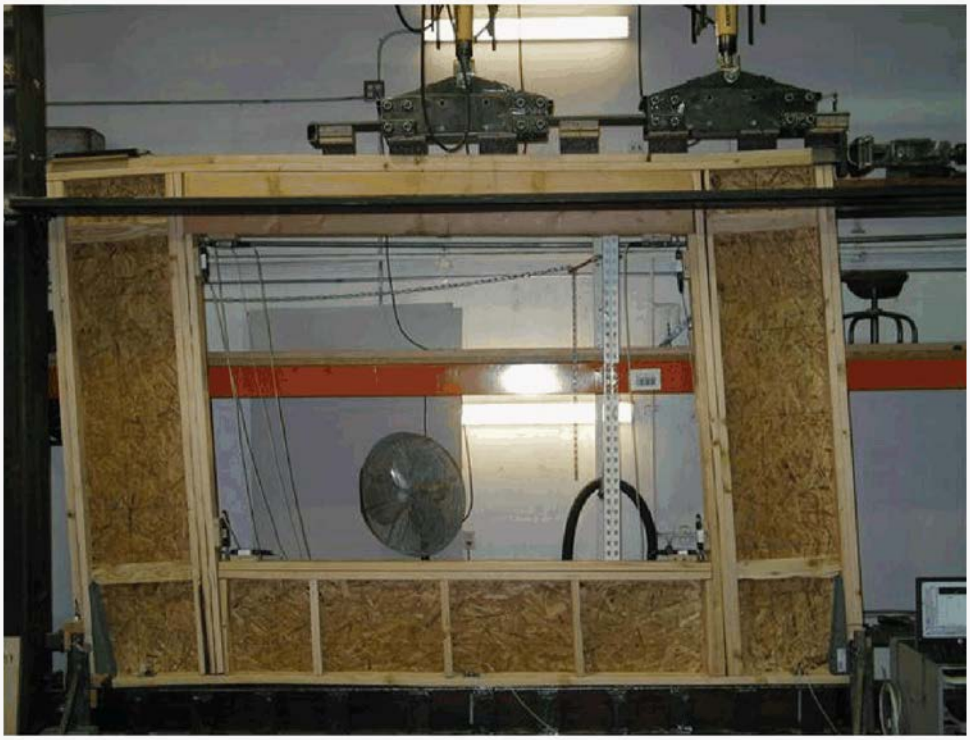


FIGURE F5

WALL 6A, SHEATHING TEARING, TOP EAST STRAP

FIGURE F6

WALL 6A, SHEATHING TEARING, TOP WEST STRAP

FIGURE F7

WALL 6A, SHEATHING TEARING, BOTTOM WEST STRAP

FIGURE F8

WALL 6A, SHEATHING TEARING, BOTTOM EAST STRAP

FIGURE F9

WALL 7B, NAIL HEAD PULL-OUT FROM BOTTOM OF PANEL

FIGURE F10

WALL 9B, NAIL WITHDRAWAL

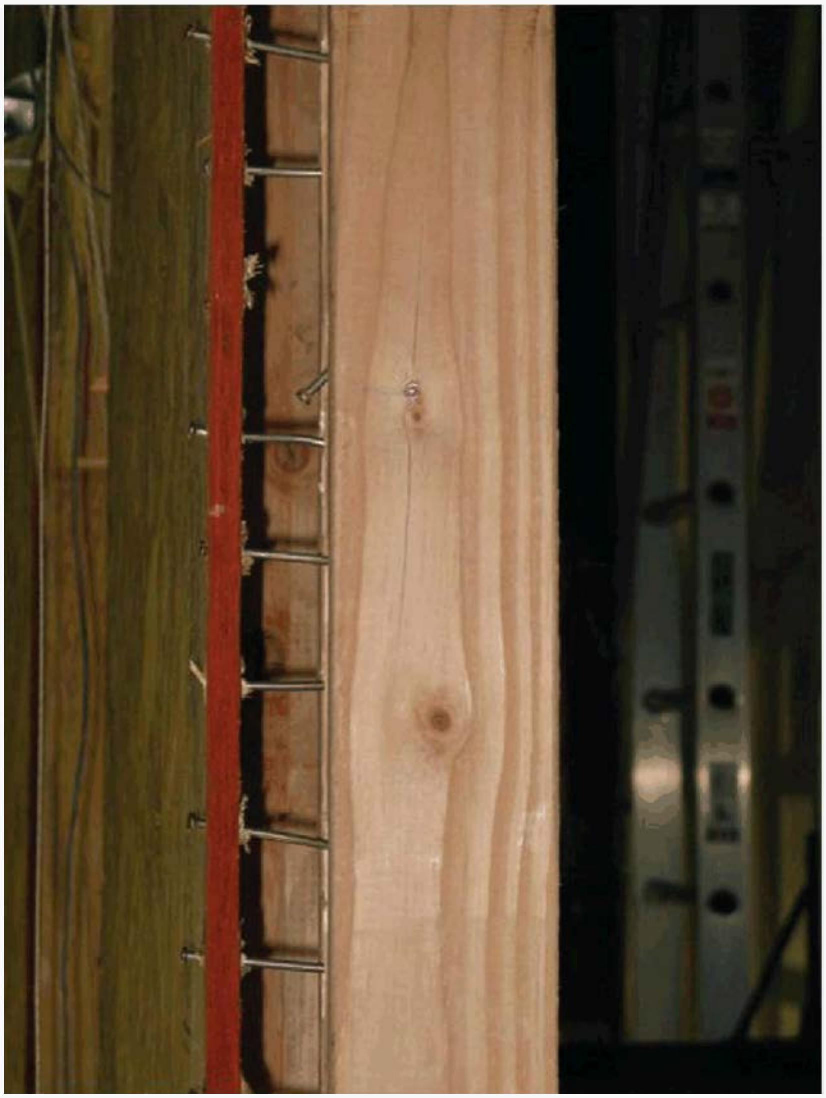


FIGURE F11

WALL 12B, SHEATHING TEARING

FIGURE F12

WALL 6A, SHOWING STRAPS AND DISPLACEMENT GAGES

FIGURE F13

WALL 10B, SHOWING INSTRUMENTED HOLD DOWNS AND ANCHOR BOLTS

PART 2: MODELING FORCE TRANSFER AROUND SHEAR WALL OPENINGS

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University of British Columbia, Vancouver, BC

ABSTRACT

A nonlinear finite element based structural analysis program Wall2D has been developed to model the force transfer around openings of perforated shear walls. The kernel of Wall2D is the model of the nonlinear load-slip response of the frame to sheathing wall connectors. Model predictions were compared with the test results. Since the perforated shear walls encountered failure modes such as tearing and buckling of sheathing panels, failure of framing members and connections, the load path within the wall systems changed once such failure modes were encountered. As a result, Wall2D over predicted the ultimate capacity of the perforated shear walls and can only be used to consider the response up to the design capacity. Comparisons of maximum force transfer around openings (FTAO) at the wall design capacity from the test results, WALL2D model and simplified analogs are presented. The prediction error range of the computer model at the wall design capacity is from –15.4% to +4.3%.

The Drag Strut method can either under predict or over predict the maximum FTAO. The Cantilevered Beam, Coupled Beam, and Diekmann's methods on the other hand are very conservative. When compared to the test data, using Diekmann's method as a base, a reduction correction factor of 1.2 to 1.3might be considered to account for the contribution of the framing and nail elements within the wall system. Diekmann's method however is not suitable to predict the FTAO in cases when the wall segment below the opening is not available as in the case of a garage door opening. Future studies are needed to fine tune the computer model to consider the currently ignored nonlinearity and failure modes.

1.2 INTRODUCTION

The current design codes provide three solutions to wood shear walls with openings. The first one considers only full-height wall segments and ignores the contribution of wall segments above and below openings. The second one takes into account the wall segments with openings using an empirical reduction factor. The last solution is the "force transfer around openings" (FTAO) method in which shear walls are designed for the forces transferred around openings. And nails, metal straps, blocking members may be required to reinforce the corners of openings. In the last solution, rational structural analyses are needed to obtain the amount of forces transferred around openings.

Martin (2005) provided a detailed review of the common design methods of wood shear wall with openings: traditional segmented shear wall approach, drag strut method, and cantilevered beam analog. Depending on the geometry of a perforated shear wall, the drag strut and cantilevered beam methods can yield very different estimates of the forces around the openings. Diekmann (2005) provided a discussion on Martin's article and presented a method he proposed (1997) based on Vierendeel truss analog. Kolba (2000) performed a detailed experimental study on perforated wood shear walls focusing on the applicability of Diekmann's method. Although the results were inconclusive, detailed explanations of the assumptions of Diekmann's method were provided. Robertson (2004) discussed different methodologies available to an engineer for analyzing and designing force transfer around openings in plywood sheathed shear walls. He discussed building codes requirements and analyzed examples of several perforated shear wall configurations using the drag strut method, cantilevered beam method, and coupled beam analogy (a variation of Diekmann's method but seems to lack some equilibrium rigor). Large differences in estimated force transfer around opening were found. Lam (2010) also reviewed four commonly used "rational"design methods (Drag Strut, Cantilevered Beam, Coupled Beam, and Diekmann's method) and compared the estimations of maximum transfer forces of five cases of shear wall with openings. The results indicated that depending which "rational"analysis method is used the results can vary significantly. This reinforces the need to study the FTAO problem carefully to enhance our understanding.

In this study, a finite element model "WALL2D" has been used to estimate the FTAO in twelve different types of shear walls with different sizes of opening, widths of full-height wall piers and construction techniques, as shown in Figure 1. Monotonic loading was applied on the top of each wall and internal forces in the FTAO metal straps, hold-downs, and anchor bolts were obtained. The modeling predictions were compared with the shear wall test results provided by the APA laboratory for the model verification.

2.2 WALL 2D – SHEAR WALL MODEL

The WALL2D model was developed at the University of British Columbia (UBC) to study the behavior of panel-sheathed wood shear walls under monotonic loads and cyclic loads. It was compiled in Intel Visual Fortran Compiler V10.1 (Intel, 2005). This original version of the WALL2D model consists of linear elastic beam elements for the framing members, orthotropic plate elements for the sheathing panels, linear springs for framing connections, and oriented nonlinear springs for panel-frame nailed connections. A special feature of this wall model is the implementation of a mechanics-based nail connection model, called HYST, to account for the nonlinear springs connecting the framing members to the sheathing panels. The current version of the HYST model can fully address strength and stiffness degradation as well as the pinching effect in a typical hysteresis of a panel-frame nail connection. In this project, to study the FTAO in the shear walls, two types of spring elements have been added. One is the tension-only springs for hold-downs, anchor bolts, and metal straps around the wall openings; the other one is the compression-only springs to account for contacts between wood members and contacts between sill plates and the foundation.

The detailed introduction of the WALL2D model as well as the HYST model can be found in a research paper submitted to Journal of Structural Engineering for publication (Li et al. 2011).

FIGURE 1

SHEAR WALL CONFIGURATIONS AND INSTRUMENTATIONS

Wall 1

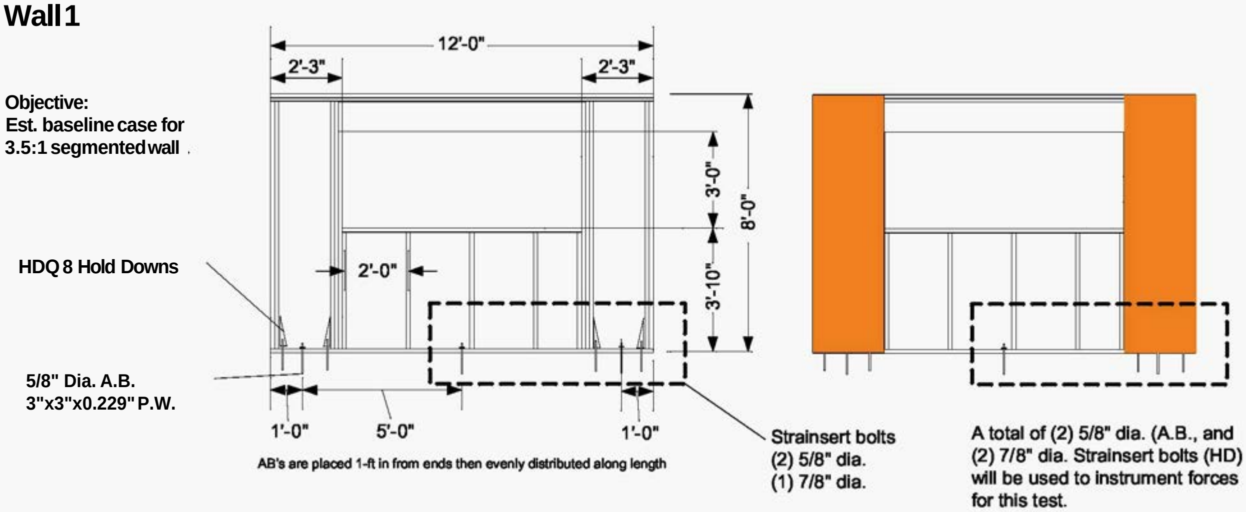
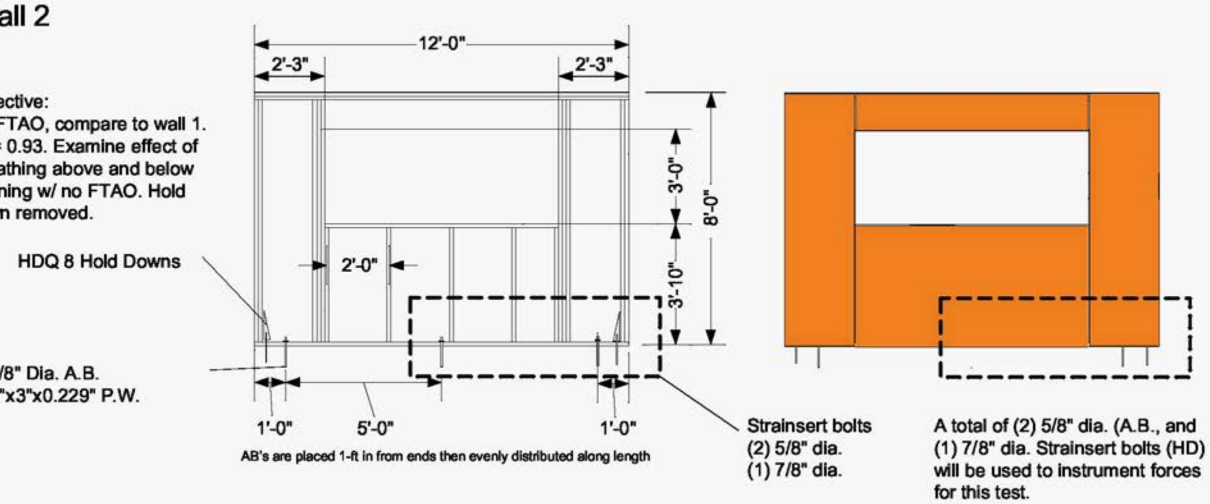


FIGURE 1 (Continued)

SHEAR WALL CONFIGURATIONS AND INSTRUMENTATIONS

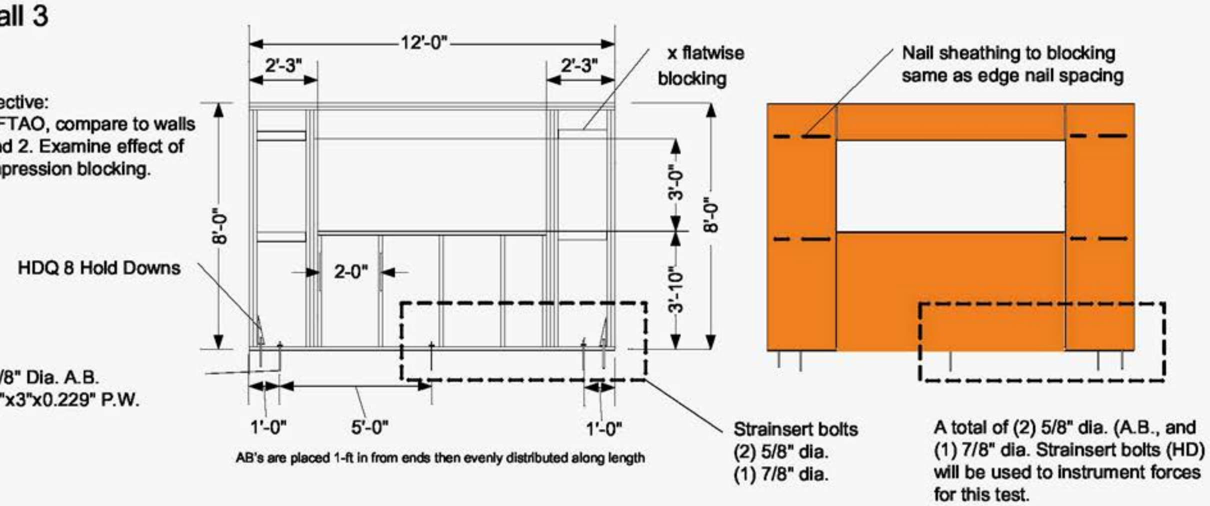
Wall 2

Objective:
No FTAO, compare to wall 1. C_o = 0.93. Examine effect of sheathing above and below opening w/ no FTAO. Hold down removed.



Wall 3

Objective:
No FTAO, compare to walls 1 and 2. Examine effect of compression blocking.



Wall 4

Objective:
FTAO, compare to wall 1 Examine effect of straps.

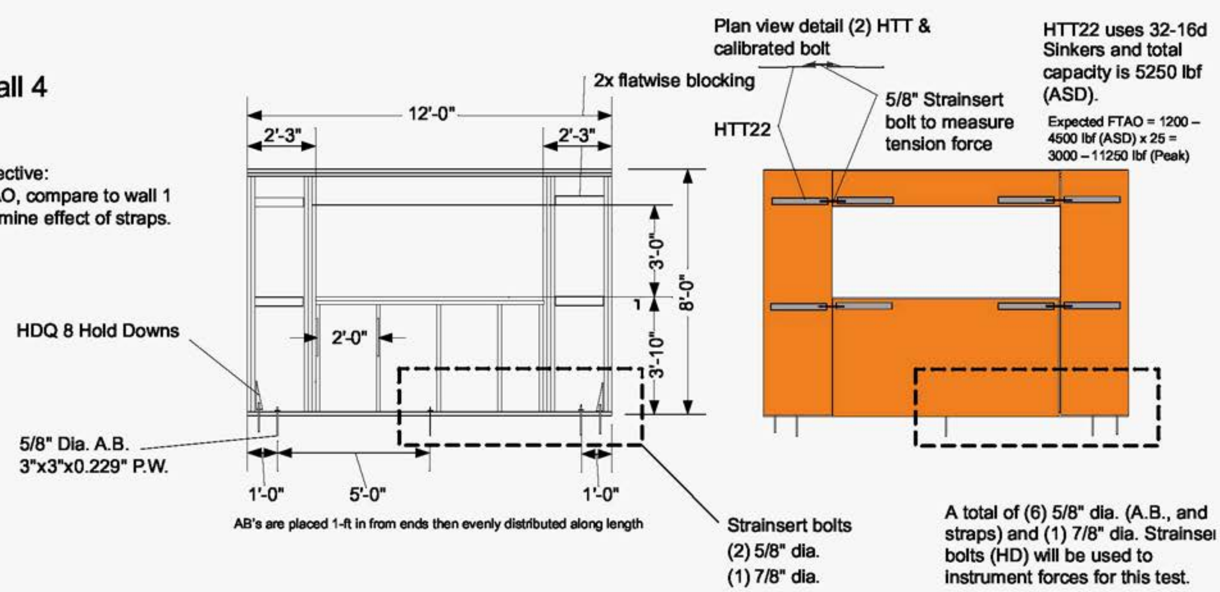
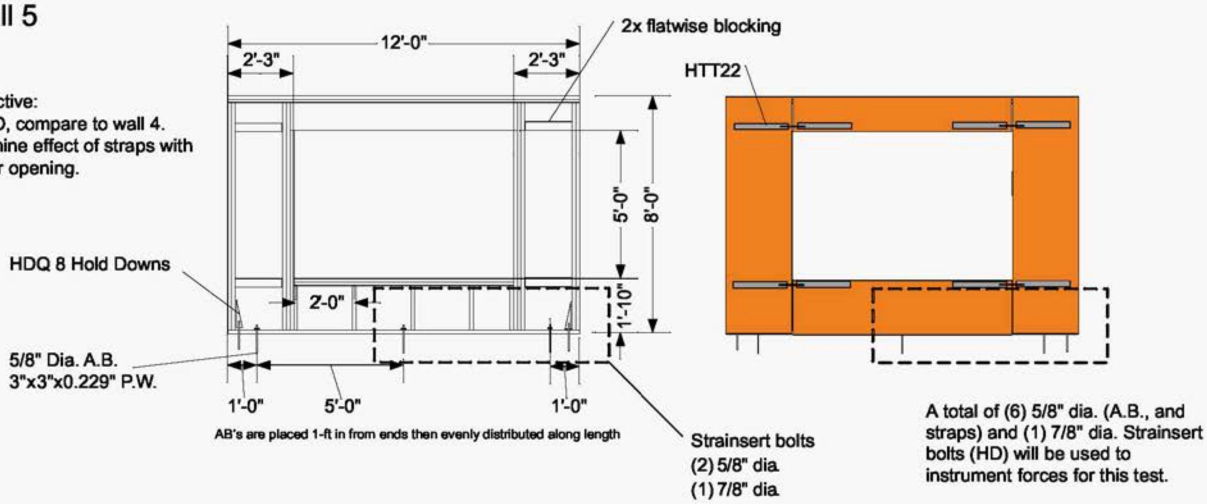


FIGURE 1 (Continued)

SHEAR WALL CONFIGURATIONS AND INSTRUMENTATIONS

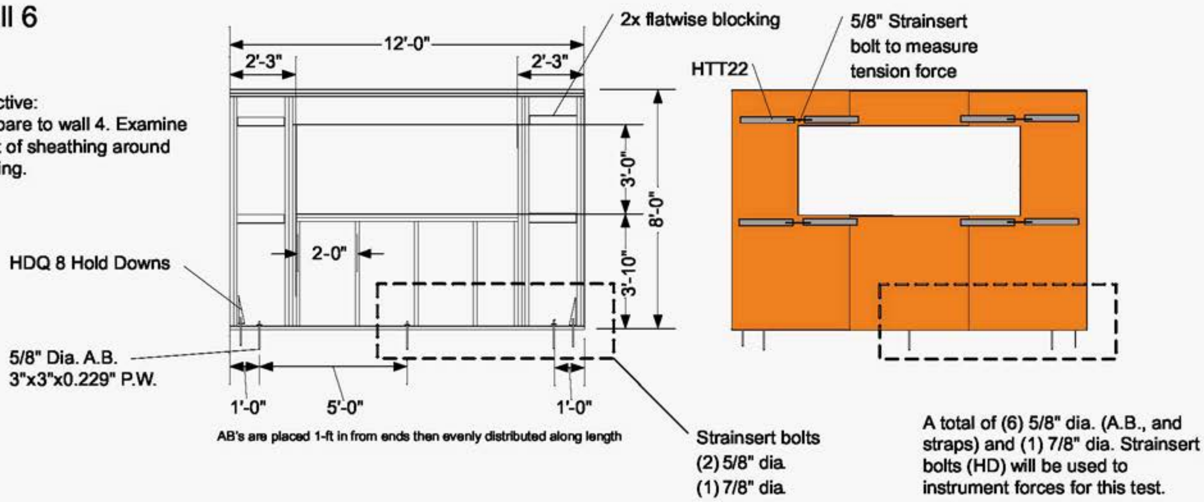
Wall 5

Objective:
FTAO, compare to wall 4.
Examine effect of straps with larger opening.



Wall 6

Objective:
Compare to wall 4. Examine effect of sheathing around opening.



Wall 7

Objective:
Est. baseline case for 2:1 segmented wall.

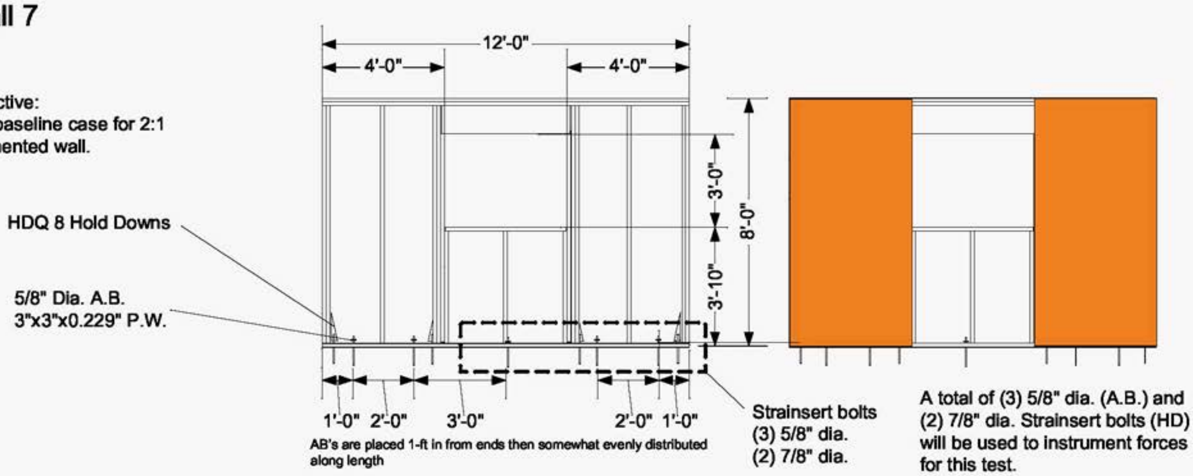
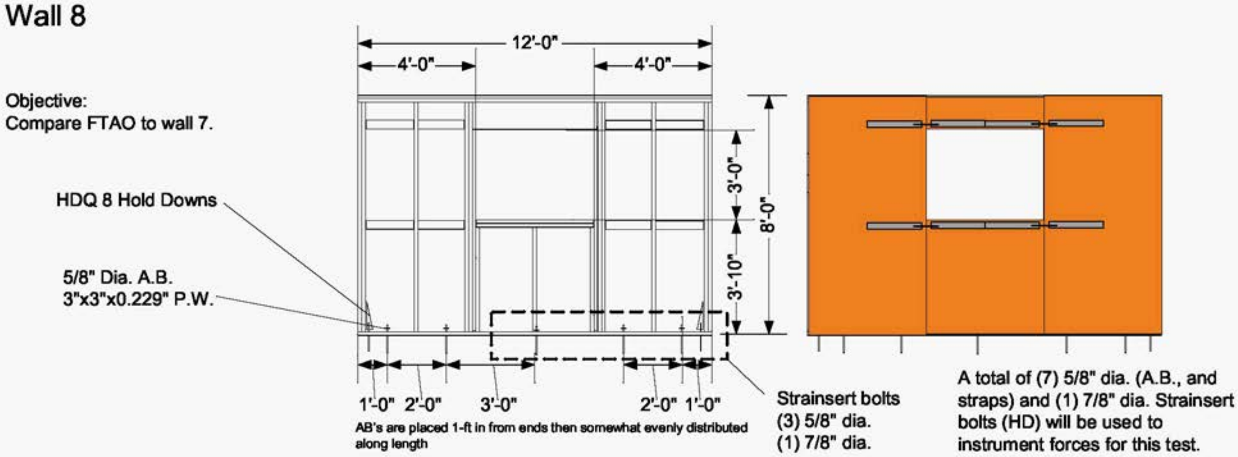


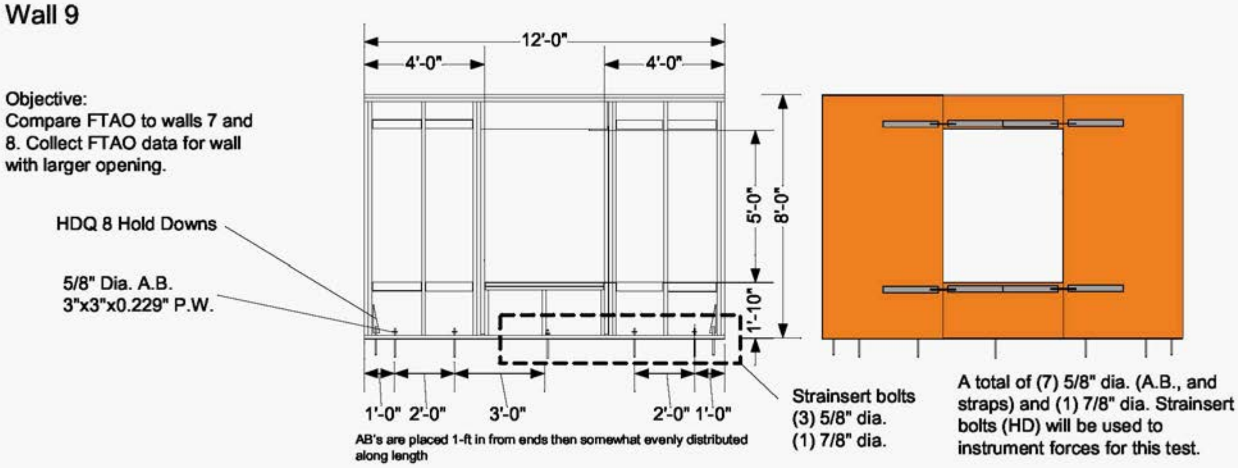
FIGURE 1 (Continued)

SHEAR WALL CONFIGURATIONS AND INSTRUMENTATIONS

Wall 8



Wall 9



Wall 10

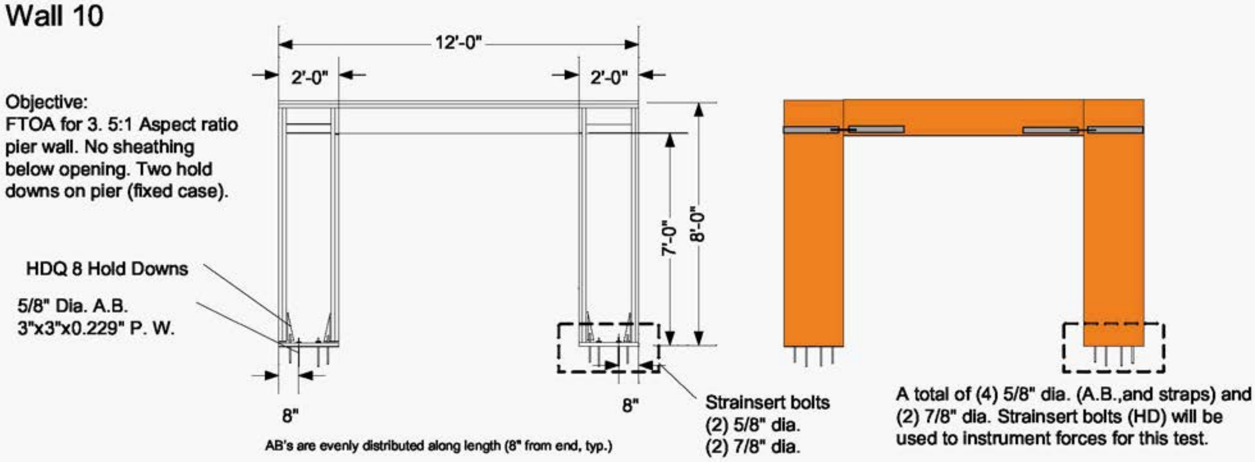
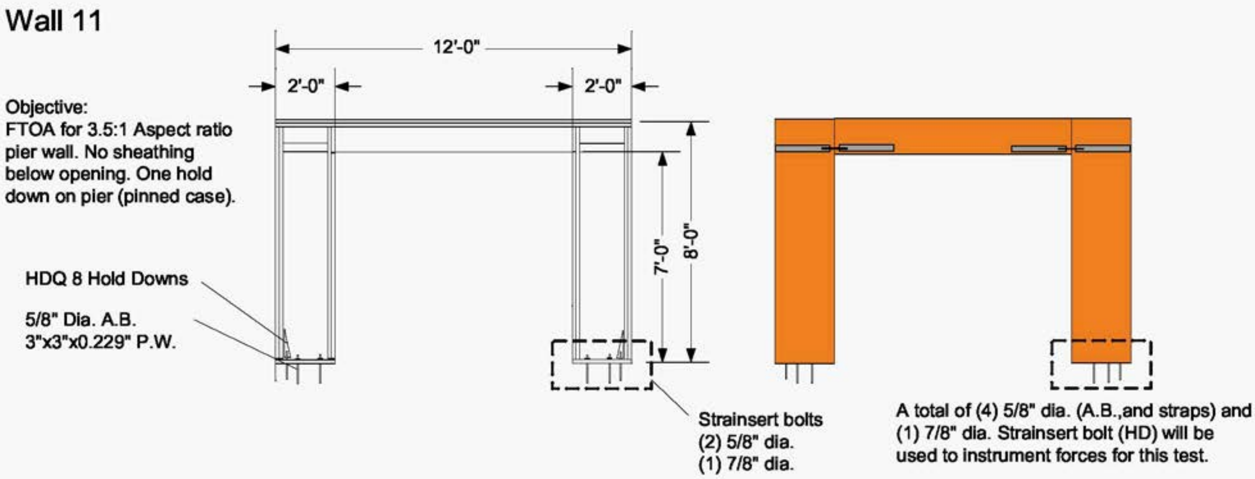
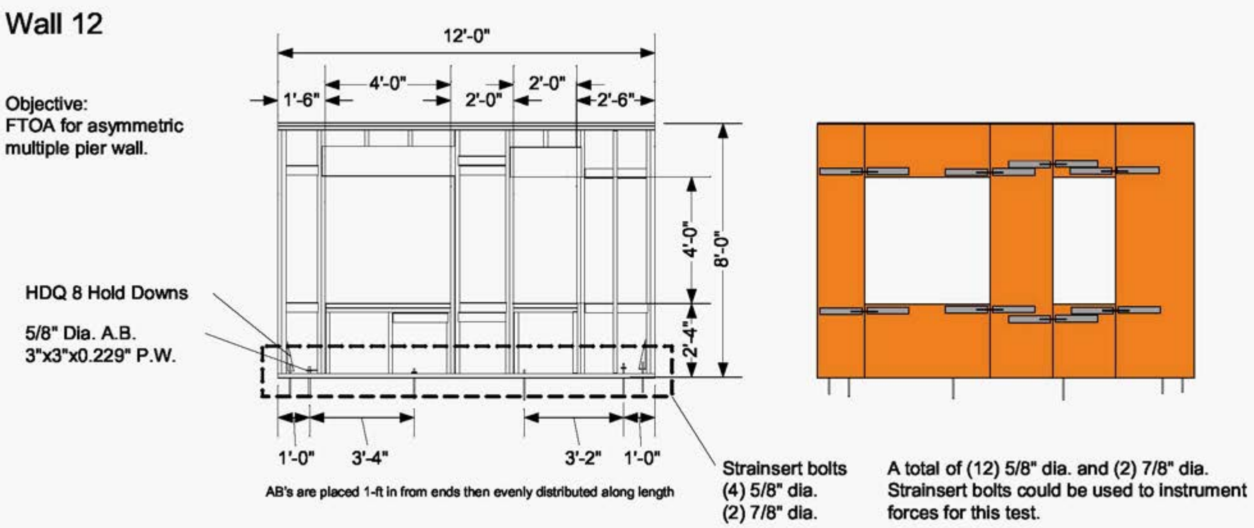


FIGURE 1 (Continued)

SHEAR WALL CONFIGURATIONS AND INSTRUMENTATIONS





2.3 MODEL INPUT

To calibrate the HYST nail model parameters (Foschi et al., 2010; Li et al., 2011) implemented in WALL2D model, nail connection tests have been conducted at Timber Engineering and Applied Mechanics Laboratory at UBC. In each nail connection, a 10d common nail fastener was used to connect a piece of 2x4 Douglas-fir lumber and a piece of 1/2-in.-thick OSB sheathing panel. A total of 15 specimens were tested under monotonic loading and cyclic loading. The CUREE near-fault protocol and the CUREE basic/standard protocol were used for the cyclic tests. Figure 2 shows the test setup of the nail connections.

FIGURE 2

SCHEMATICS OF NAIL TEST CONFIGURATION

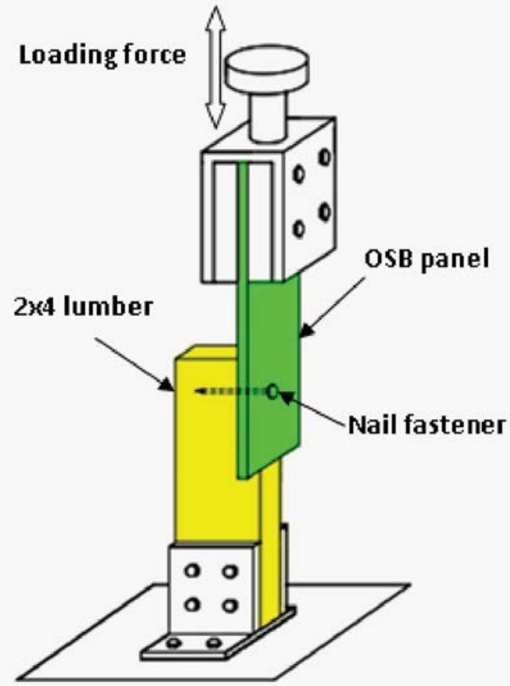


Figure 3 shows the test results in terms of load-slip curves under monotonic loading and cyclic loading. The major failure modes observed in these nail connections were the nail pull-through failures, as shown in Figure 4.

FIGURE 3

LOAD-SLIP CURVES OF NAIL CONNECTIONS TESTED UNDER MONOTONIC LOADS AND CYCLIC LOADS (1 mm = 0.03937 in.; 1 N = 0.2248 lbf)

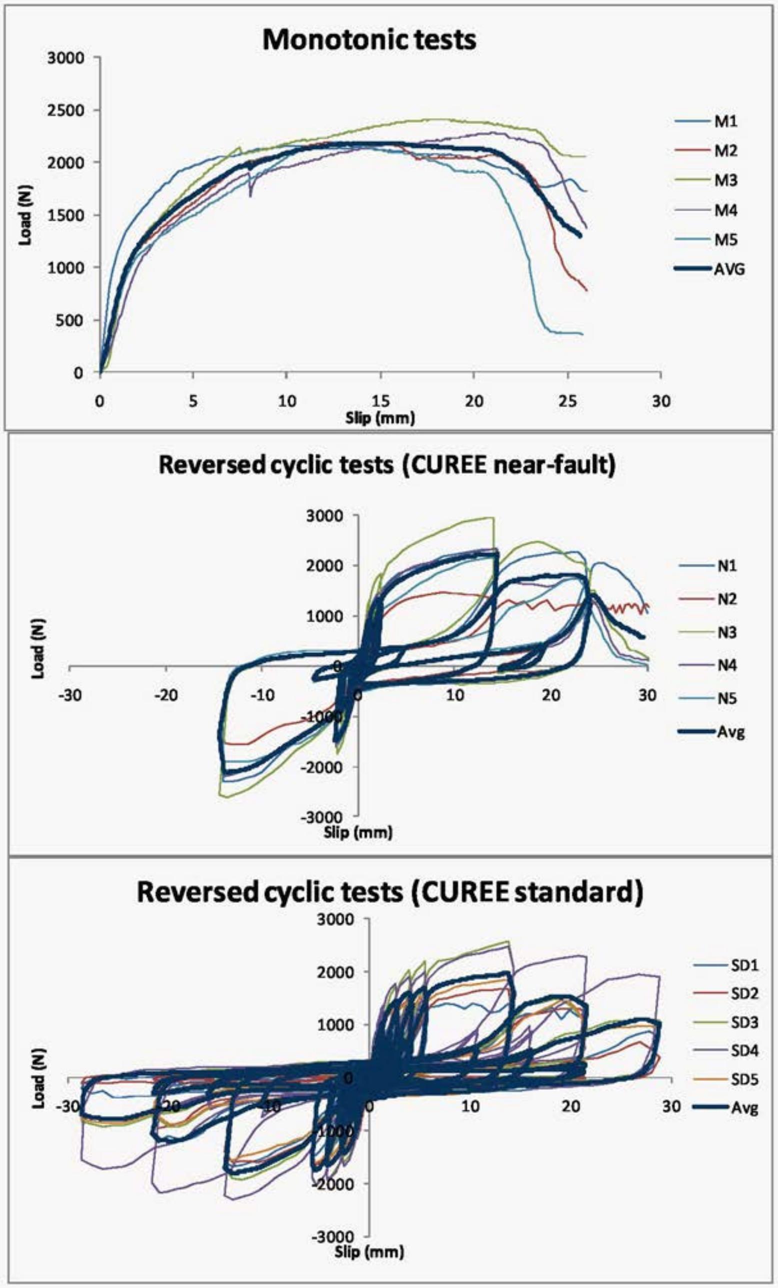


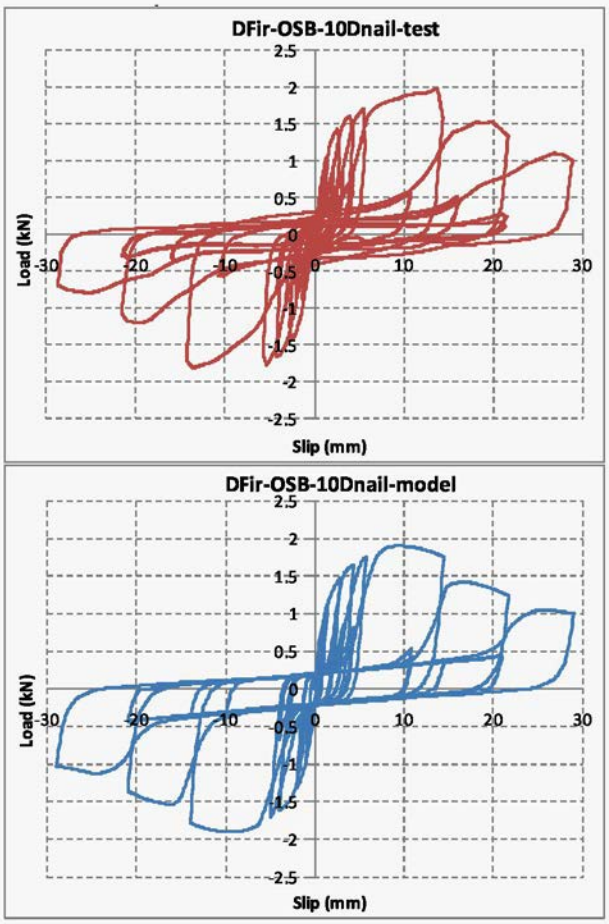
FIGURE 4

MAJOR FAILURE MODES OF THE NAIL CONNECTIONS

The average backbone curve of the load-slip curves was used to calibrate the HYST nail model parameters (Foschi et al., 2010; Li et al., 2011). Figure 5 shows the comparison between the calibrated HYST model predictions and the test results. The calibrated HYST models were then implemented in the WALL2D model to represent the load-slip hysteresis of the nailed panel-frame connections.

FIGURE 5

AVERAGE TEST LOOPS vs MODEL LOOPS OF THE NAILED CONNECTIONS (CUREE BASIC/STANDARD PROTOCOL) (1 mm = 0.03937 in.; 1 N = 0.2248 lbf)



In this study, the modulus of elasticity for Douglas-fir lumber was assumed to be 1.45 x 10^6 psi (10 GPa) (CSA, 2005). For the OSB sheathing panels, Young's moduli E_x and E_y were assumed as 0.51 x 10^6 psi (3.5 GPa) and 0.29 x 10^6 psi (2.0 GPa) along the major axis and the perpendicular axis, respectively; the shear-through-thickness rigidity G_{xy} was taken as 73 x 10^3 psi (0.5 GPa). Poisson ratios Y_{xy} and Y_{yx} were 0.13 and 0.23 (Thomas, 2003).

HDQ8 hold-downs with allowable tension loads of 7,630 lbf (33.9 kN) were used in these walls to resist shear wall uplifting. HTT22 tension ties with allowable tension loads of 4,165 lbf (18.5 kN) were used for to transfer the forces around shear wall openings. At the allowable loads, the deflections of HDQ8 and HTT22 are estimated at 0.094 in. (2.4 mm) and 0.152 in. (3.9 mm), respectively. In the wall model, the stiffness of the tension-only springs for the HDQ8 hold-downs and HTT22 ties were assumed to be 81,170 lbf/in. (14.2 kN/mm) and 27,401 lbf/in. (4.8 kN/mm), respectively. The technical information of HDQ8 and HTT22 was obtained from the website of the manufacturer (SimpsonStrong-TieCo.,Inc.,2010).

2.4 MODELING RESULTS

Figure 6 to Figure 41 show the comparisons between the modeling results and the test results in terms of the load-drift curves and the relationship between applied wall loads and the internal forces of hold-downs, anchor bolts and the metal straps for FTAO. In the computer modeling, these walls were loaded up to approximately 4 in. (100 mm) monotonically in wall drift in a displacement control mode.

FIGURE 6

WALL #1 – WALL2D MODEL

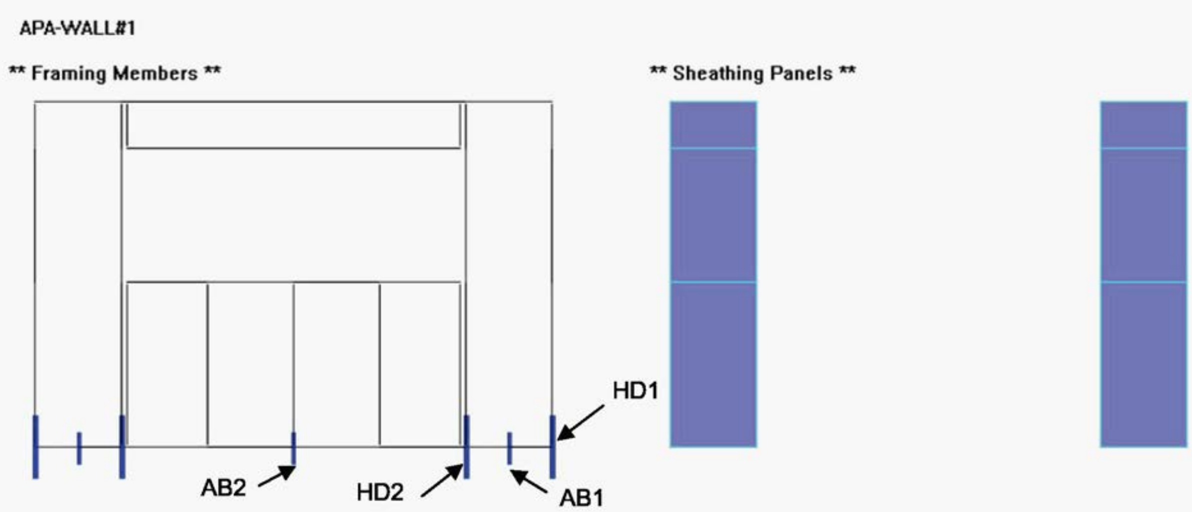


FIGURE 7

WALL #1 – MODEL PREDICTED LOAD-DRIFT CURVES vs TEST RESULTS

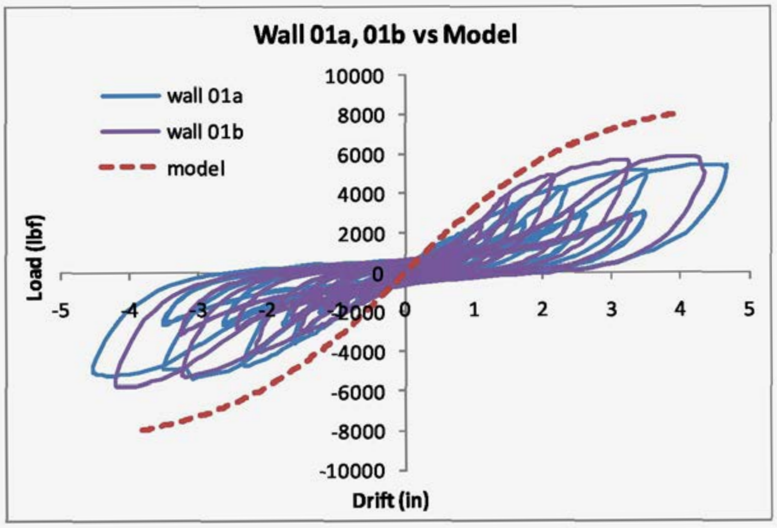


FIGURE 8

WALL #1 – MODEL PREDICTED INTERNAL FORCES vs TEST RESULTS

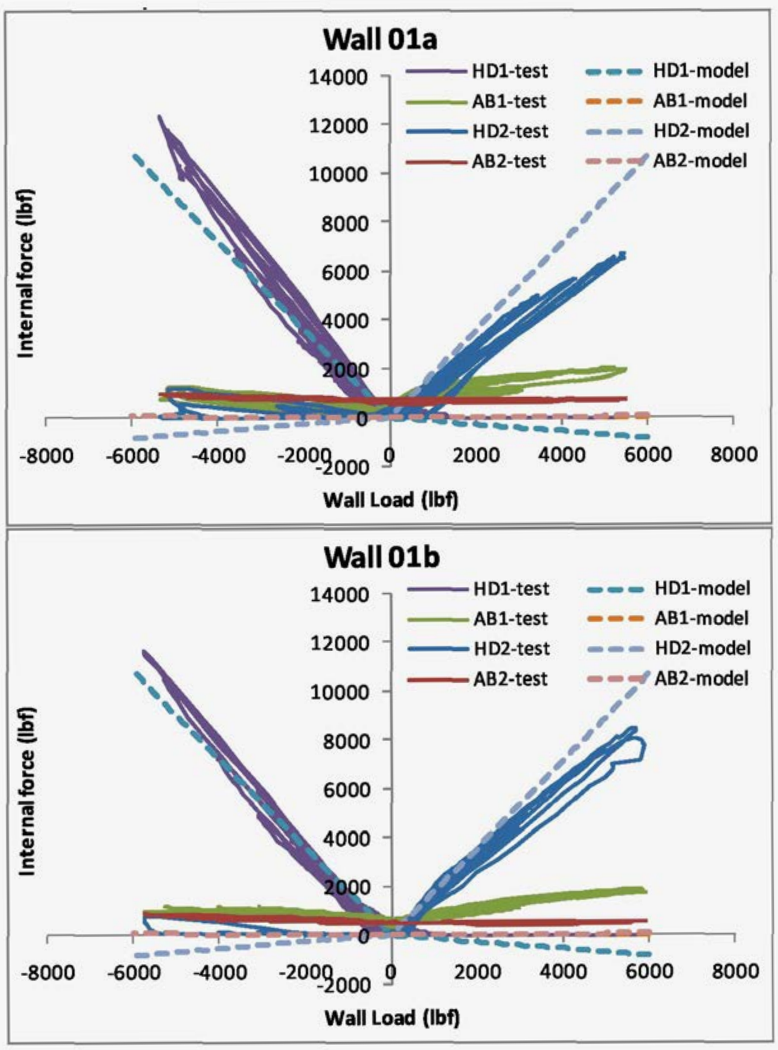


FIGURE 9

WALL #2 – WALL2D MODEL

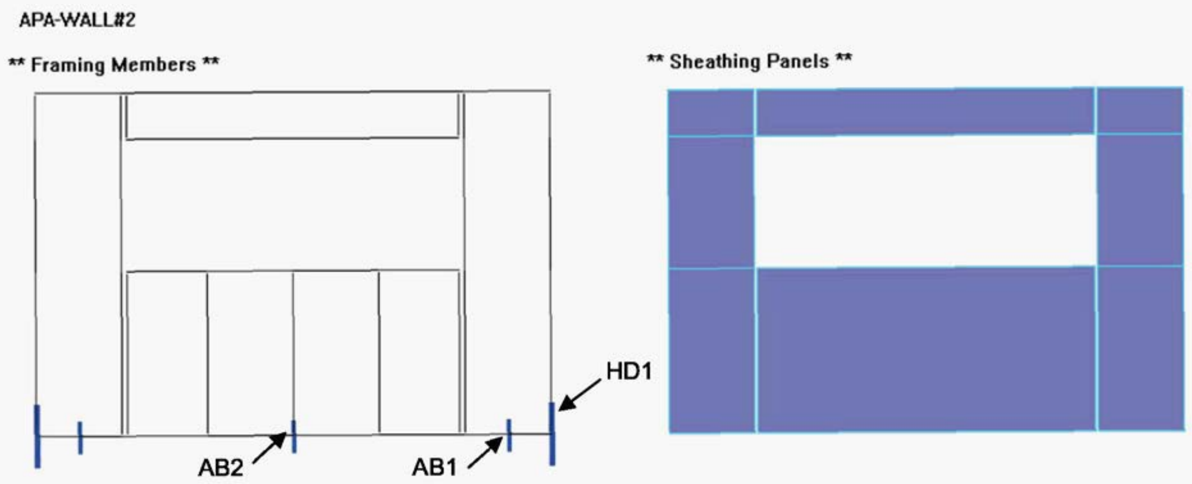


FIGURE 10

WALL 2 – MODEL PREDICTED LOAD-DRIFT CURVES vs TEST RESULTS

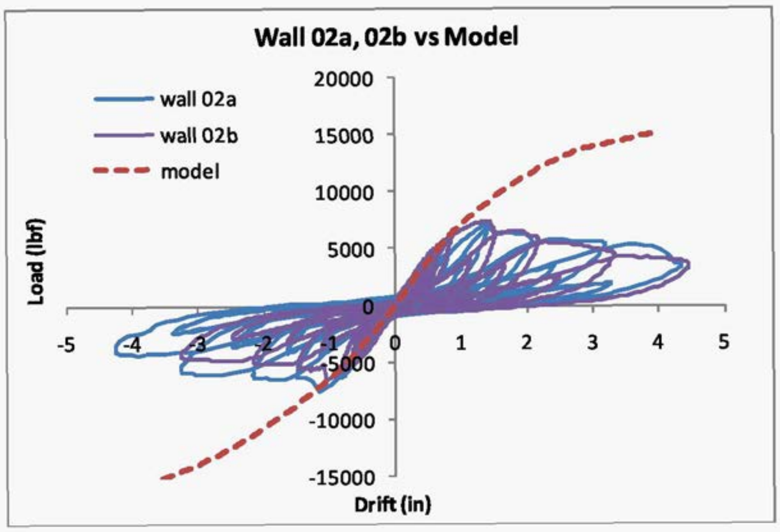


FIGURE 11

WALL #2 – MODEL PREDICTED INTERNAL FORCES vs TEST RESULTS

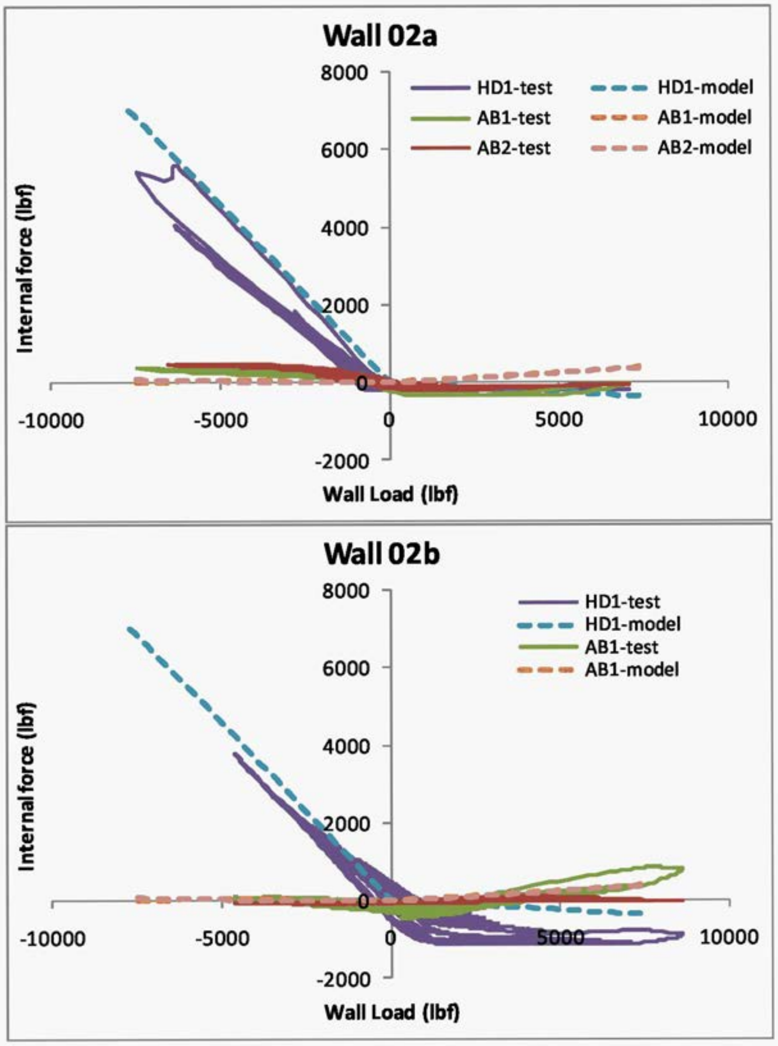


FIGURE 12

WALL #3 - WALL2D MODEL

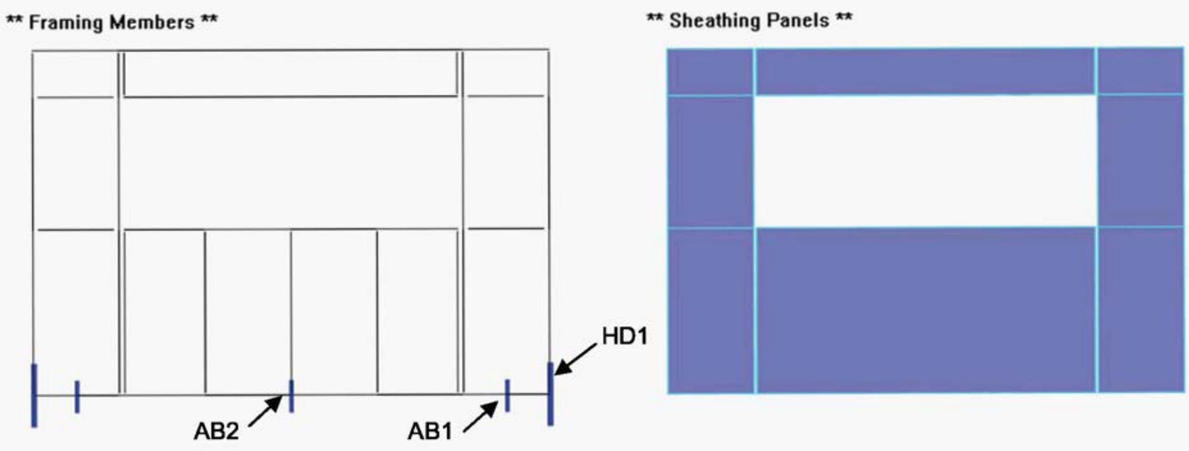


FIGURE 13

WALL #3 – MODELPREDICTED LOAD-DRIFT CURVES vs TEST RESULTS

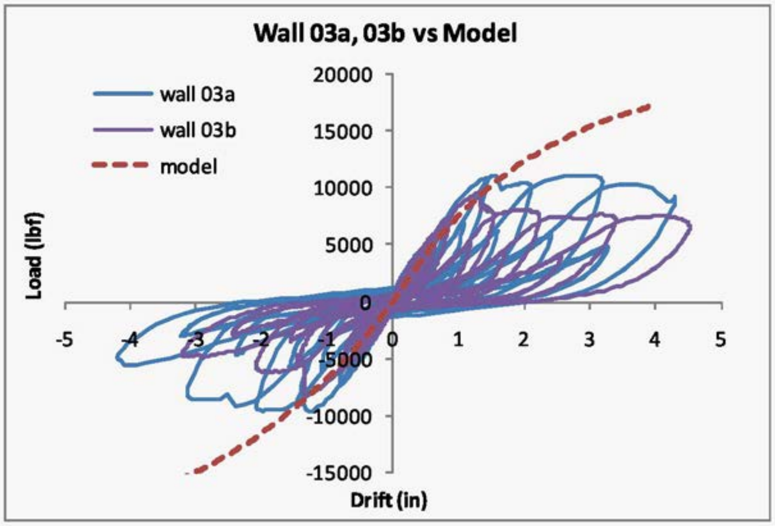


FIGURE 14

WALL #3 – MODELPREDICTED INTERNAL FORCES vs TEST RESULTS

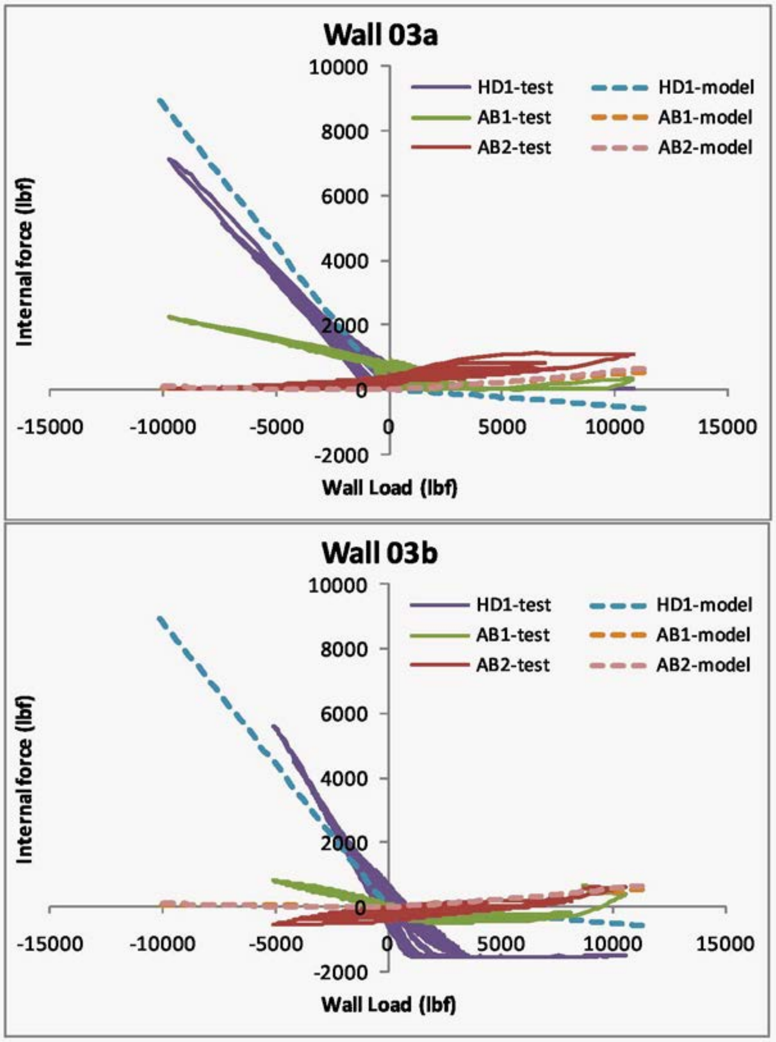


FIGURE 15

WALL #4 – WALL2D MODEL

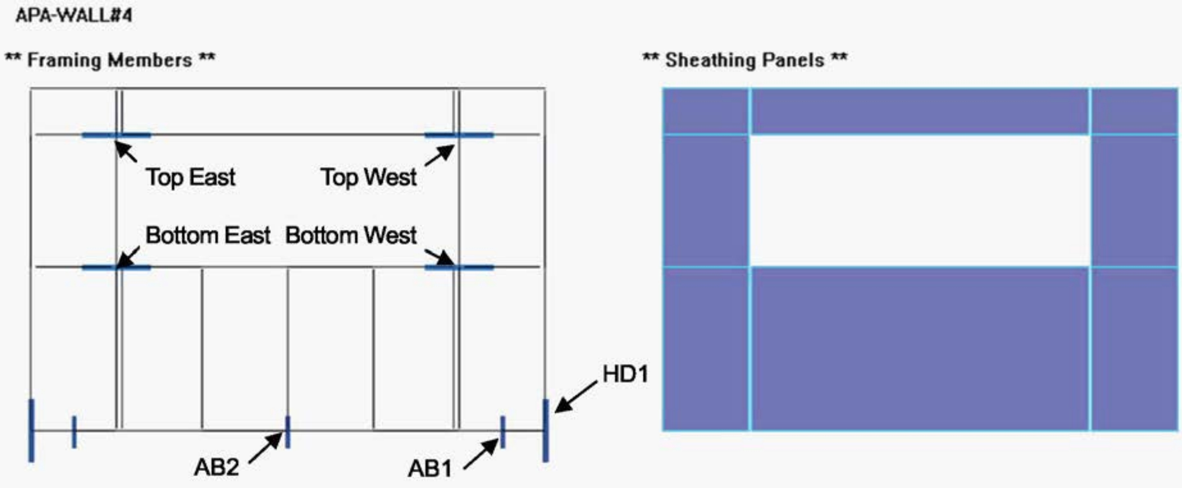


FIGURE 16

WALL #4 – MODEL PREDICTED LOAD-DRIFT CURVES vs TEST RESULTS

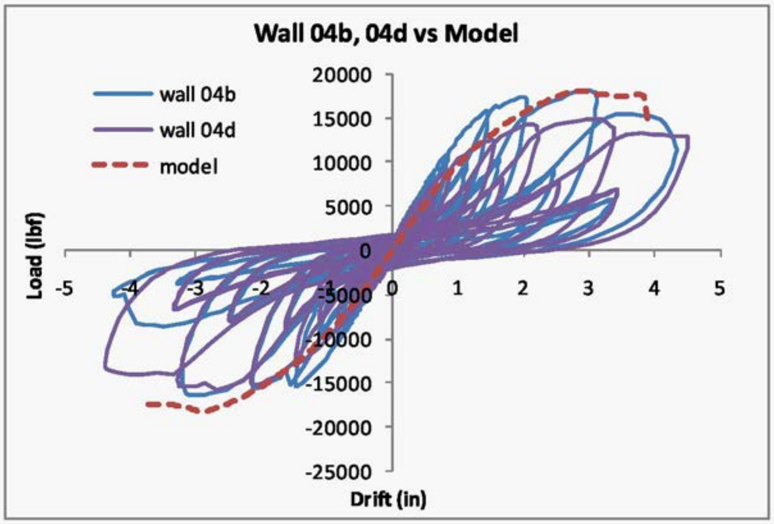


FIGURE 17

WALL #4 – MODEL PREDICTED INTERNAL FORCES vs TEST RESULTS

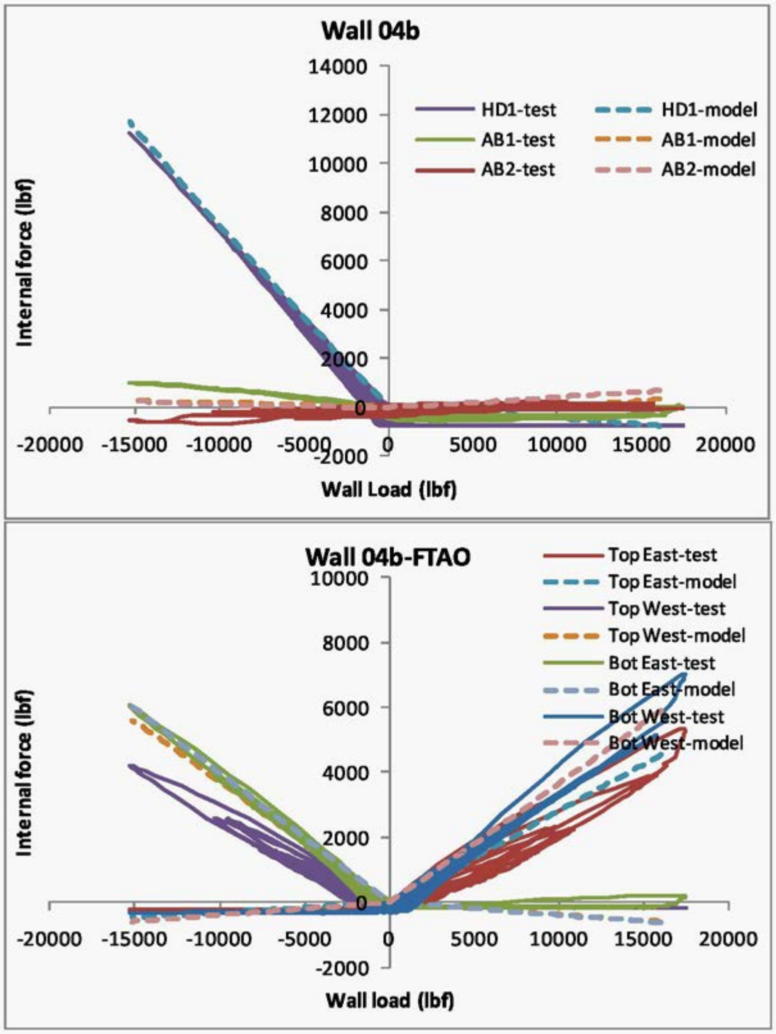


FIGURE 17 (Continued)

WALL #4 – MODEL PREDICTED INTERNAL FORCES vs TEST RESULTS

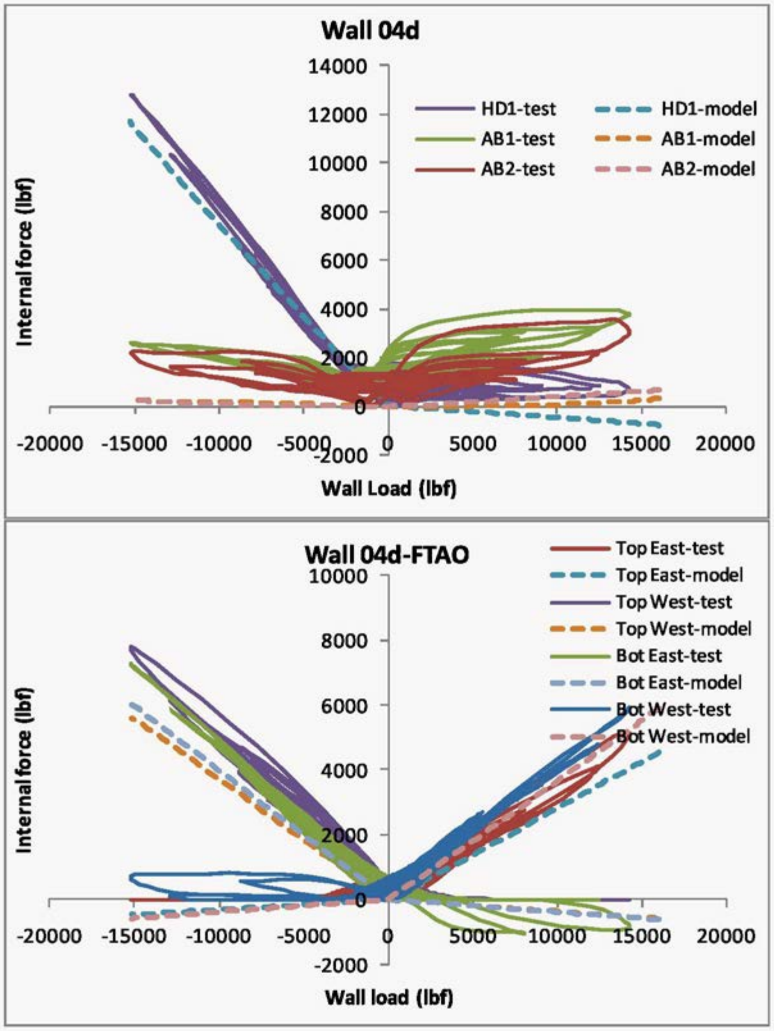


FIGURE 18

WALL #5 – WALL2D MODEL

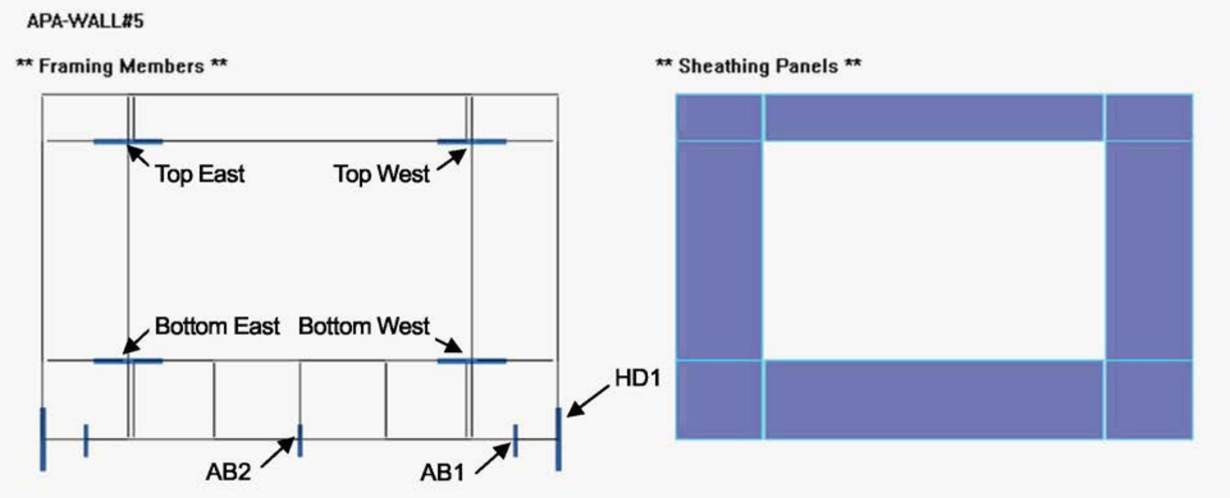


FIGURE 19

WALL #5 – MODELPREDICTED LOAD-DRIFT CURVES vs TEST RESULTS

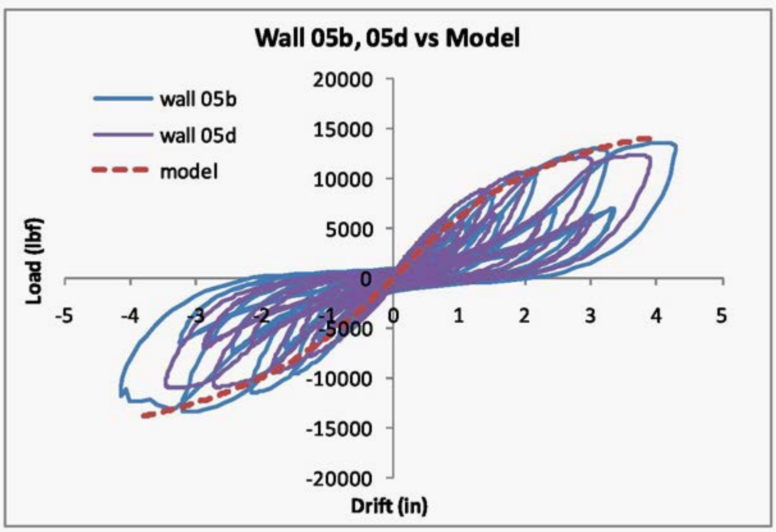


FIGURE 20

WALL #5 – MODELPREDICTED INTERNAL FORCES vs TEST RESULTS

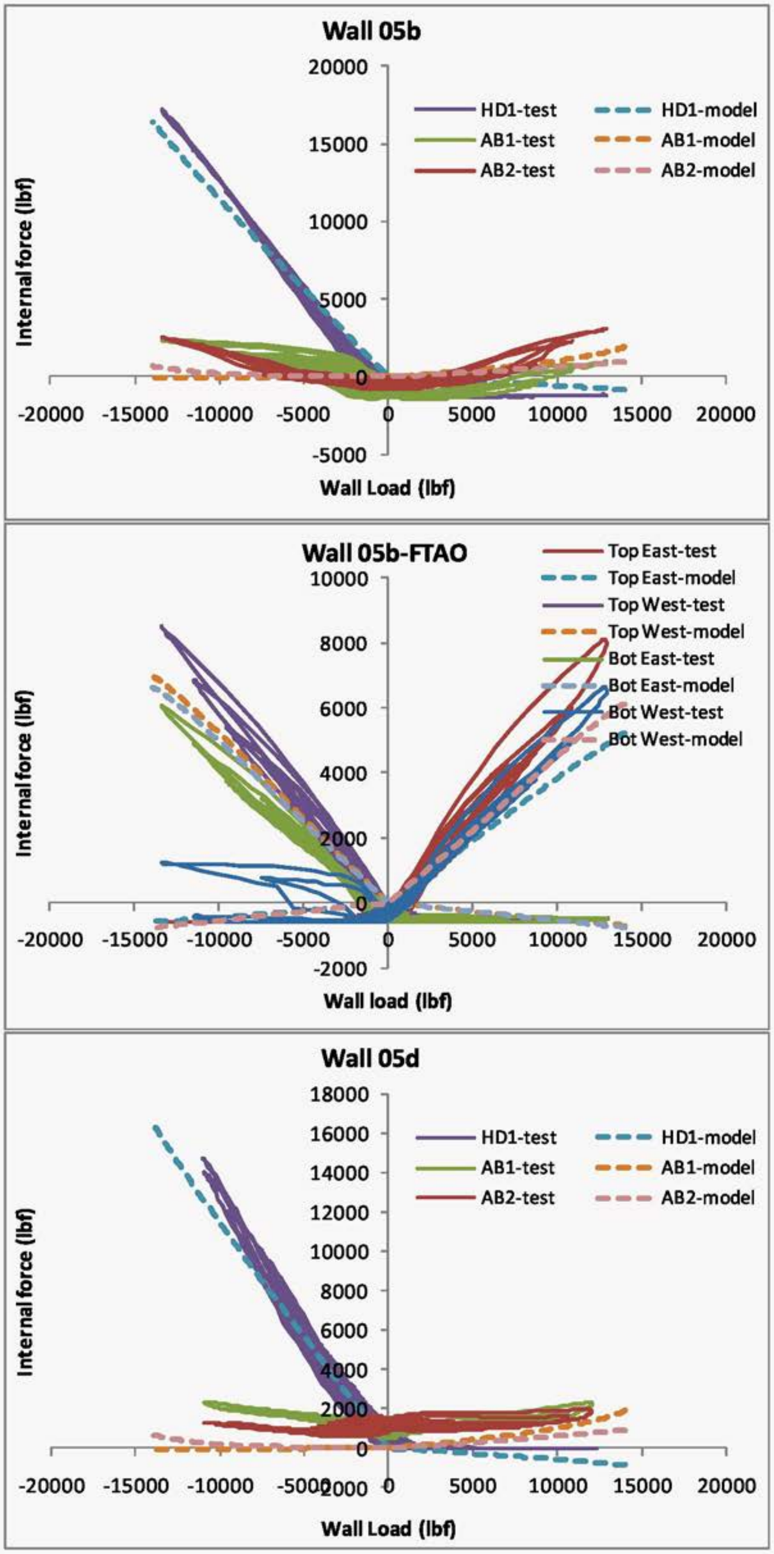


FIGURE 20 (Continued)

WALL #5 – MODELPREDICTED INTERNAL FORCES vs TEST RESULTS

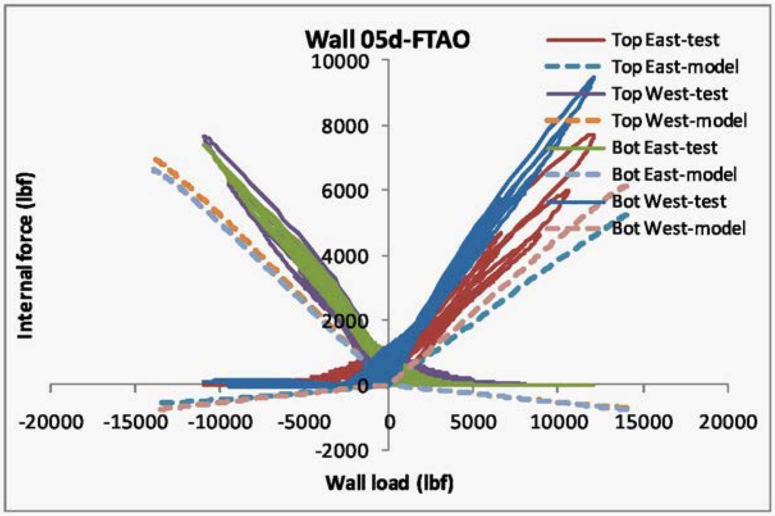


FIGURE 21

WALL #6 – WALL2D MODEL

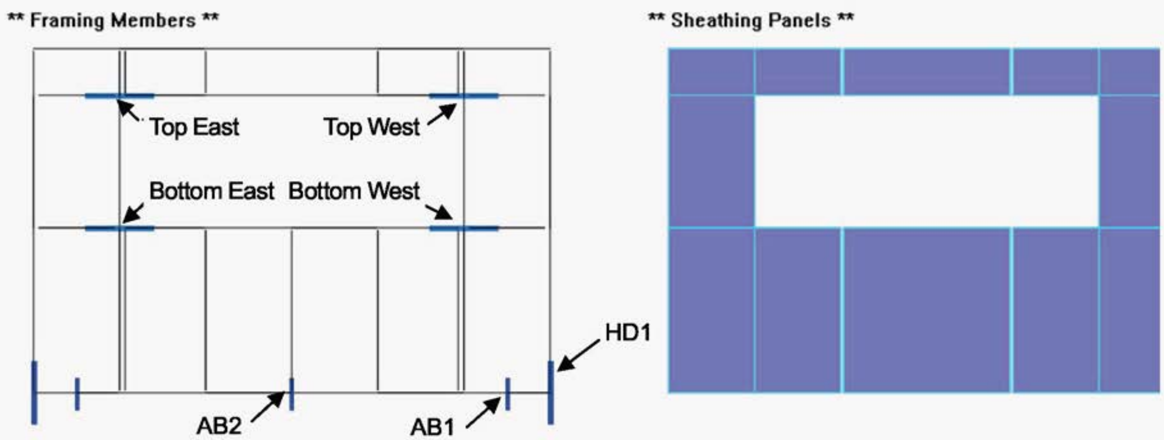


FIGURE **22**

WALL #6 – MODEL PREDICTED LOAD-DRIFT CURVES vs TEST RESULTS

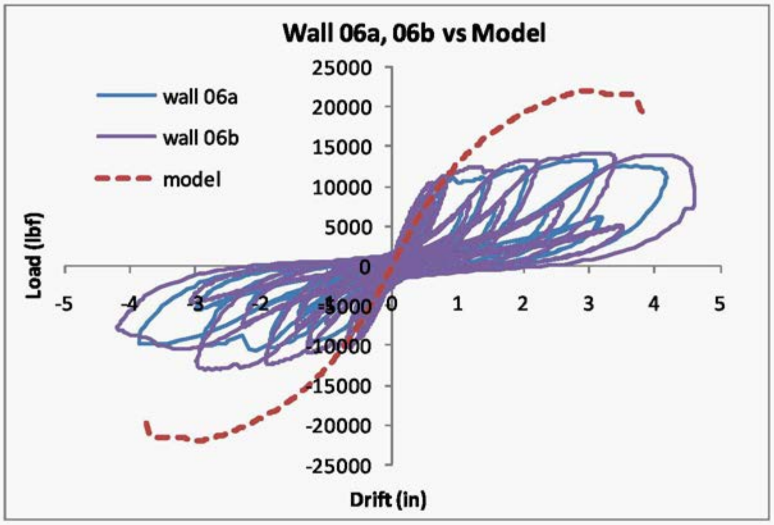


FIGURE **23**

WALL #6 – MODEL PREDICTED INTERNAL FORCES vs TEST RESULTS

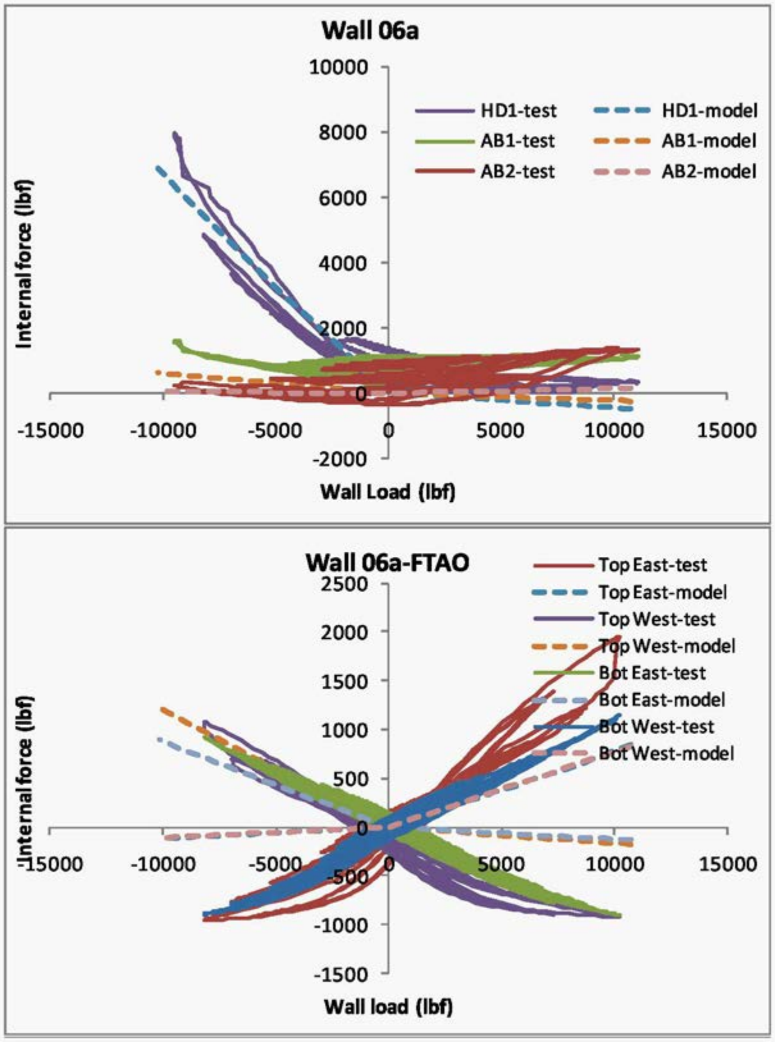
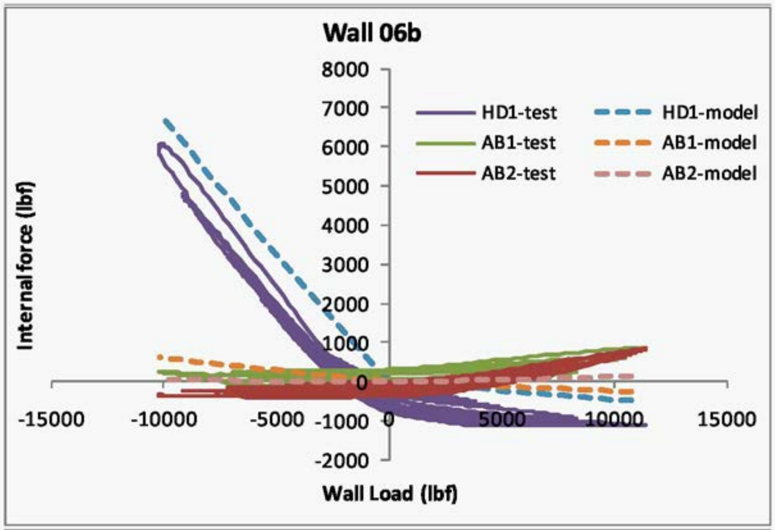


FIGURE **23** (Continued)

WALL #6 – MODEL PREDICTED INTERNAL FORCES vs TEST RESULTS



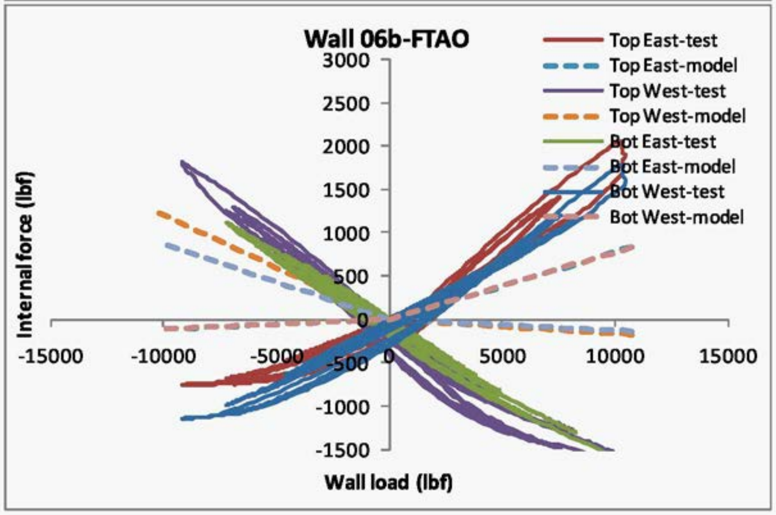


FIGURE 24

WALL #7 – WALL2D MODEL

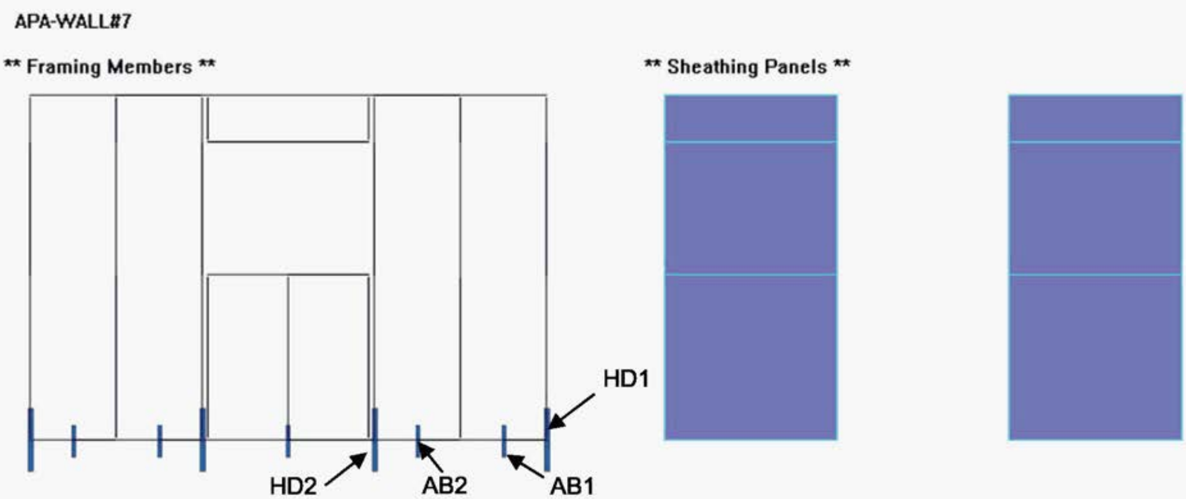


FIGURE 25

WALL #7 – MODELPREDICTED LOAD-DRIFT CURVES vs TEST RESULTS

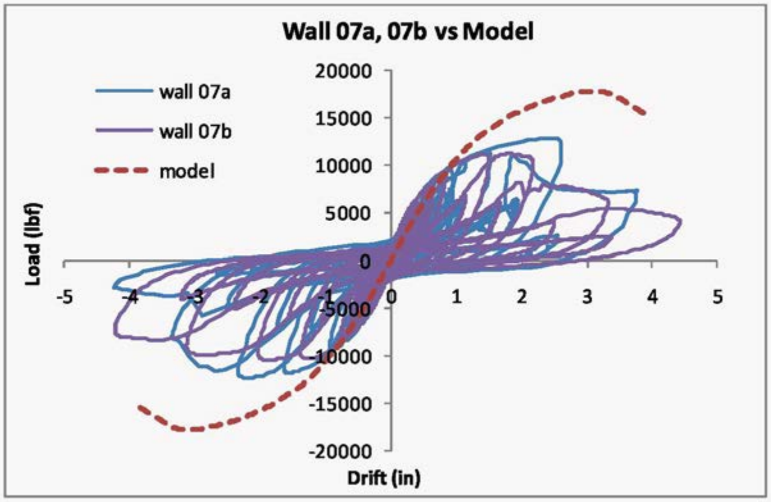
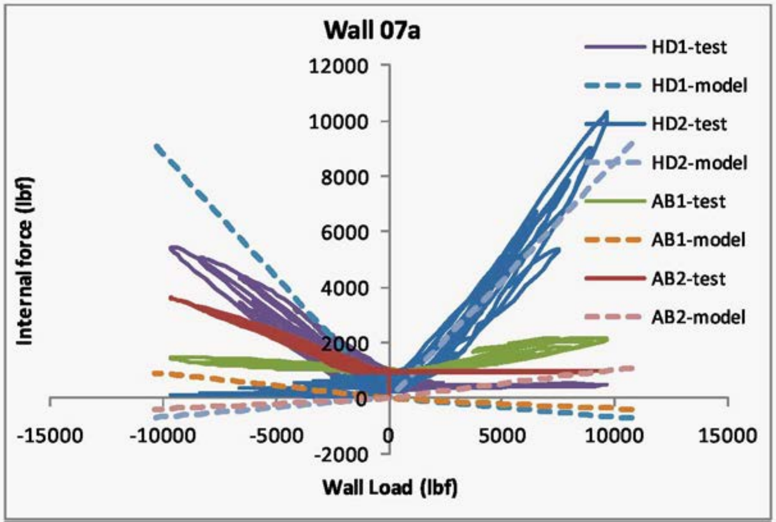


FIGURE 26

WALL #7 − MODEL PREDICTED INTERNAL FORCES vs TEST RESULTS



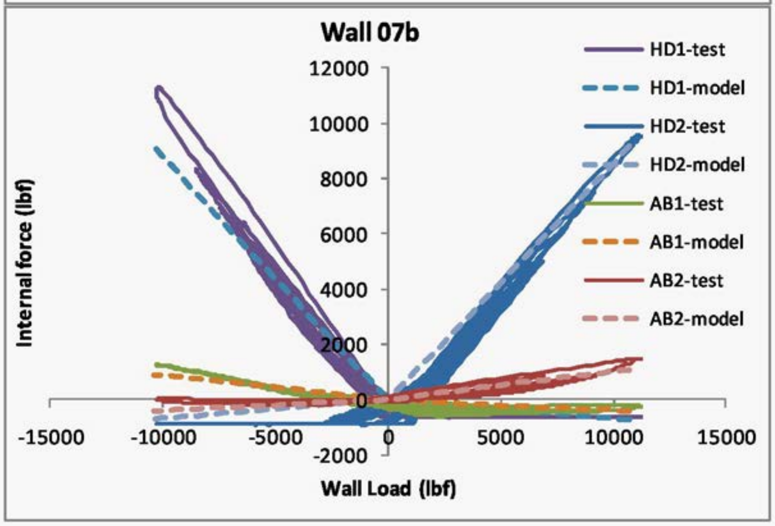


FIGURE 27

WALL #8 – WALL2D MODEL

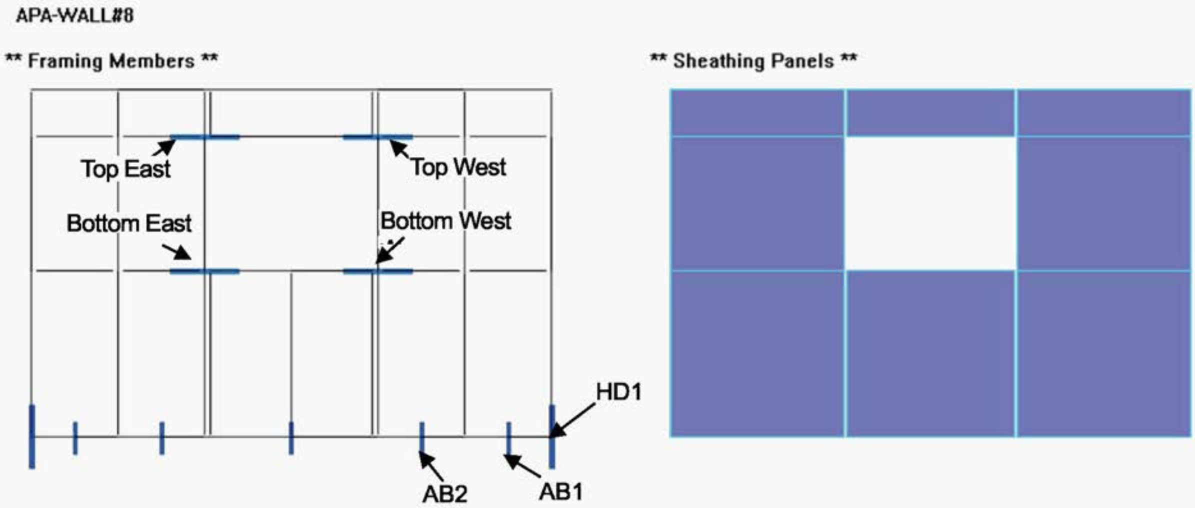


FIGURE 28

WALL #8 – MODELPREDICTED LOAD-DRIFT CURVES vs TEST RESULTS

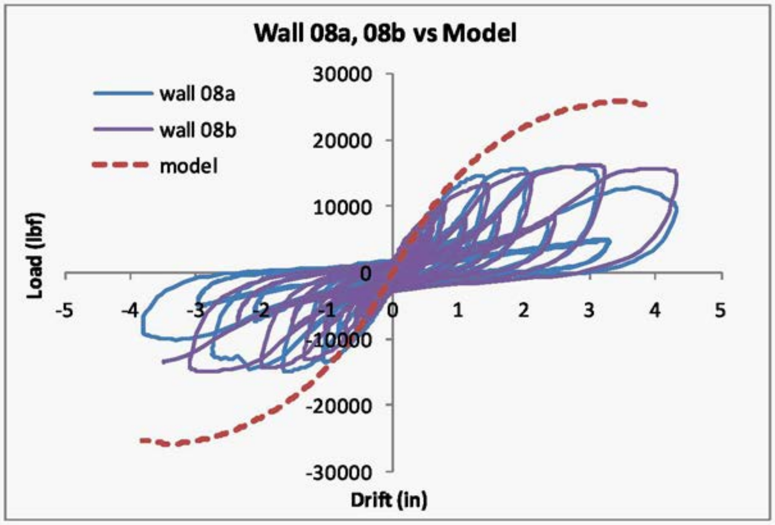


FIGURE 29

WALL #8 – MODELPREDICTED INTERNAL FORCES vs TEST RESULTS

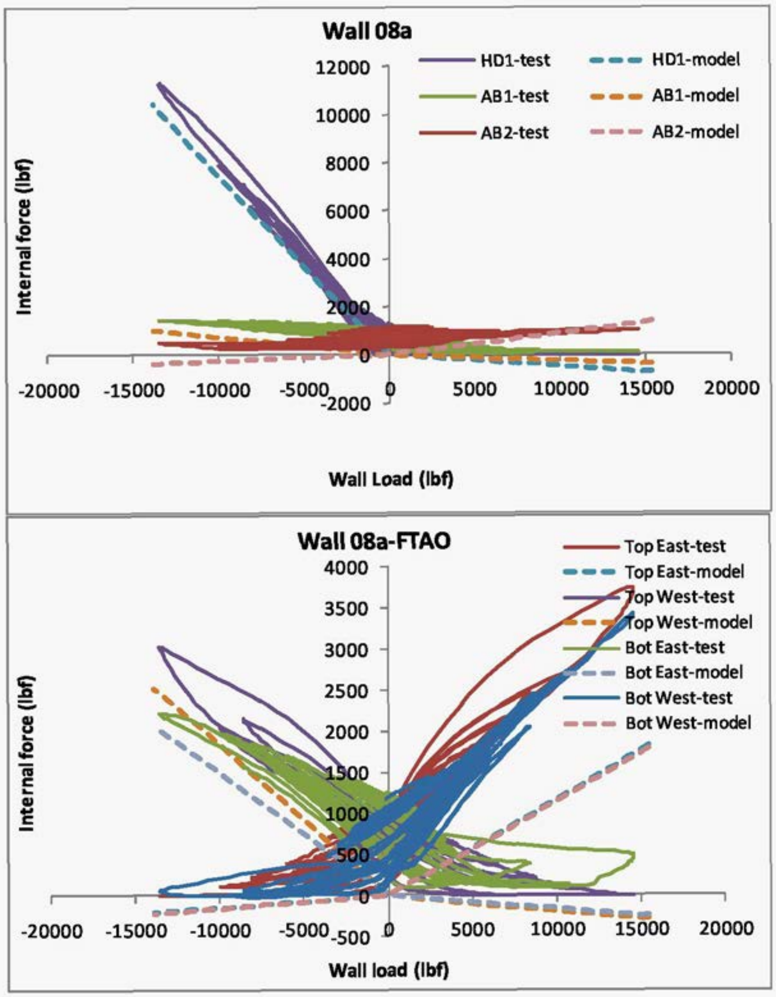


FIGURE 29 (Continued)

WALL #8 – MODEL PREDICTED INTERNAL FORCES vs TEST RESULTS

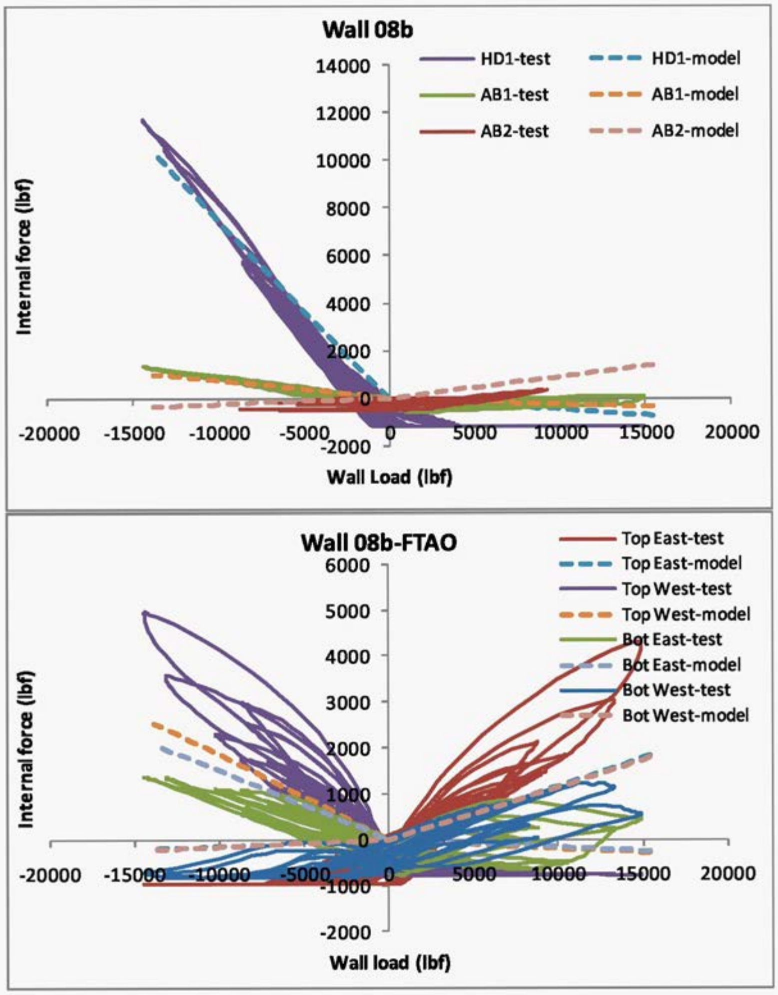


FIGURE 30

WALL #9 – MODEL PREDICTED LOAD-DRIFT CURVES vs TEST RESULTS

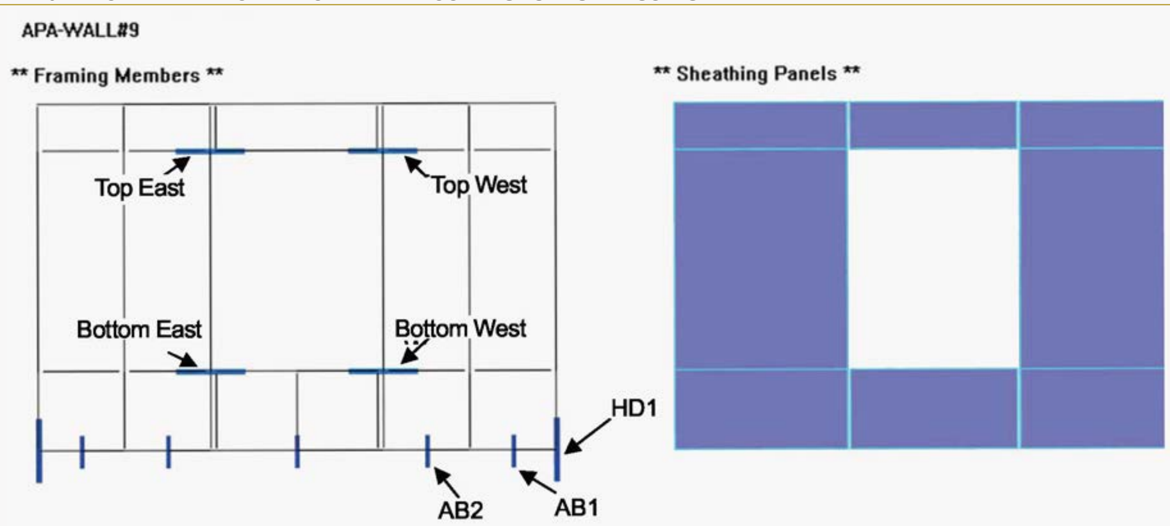


FIGURE 31

WALL #9 – LOAD-DRIFT TEST RESULTS vs MODEL

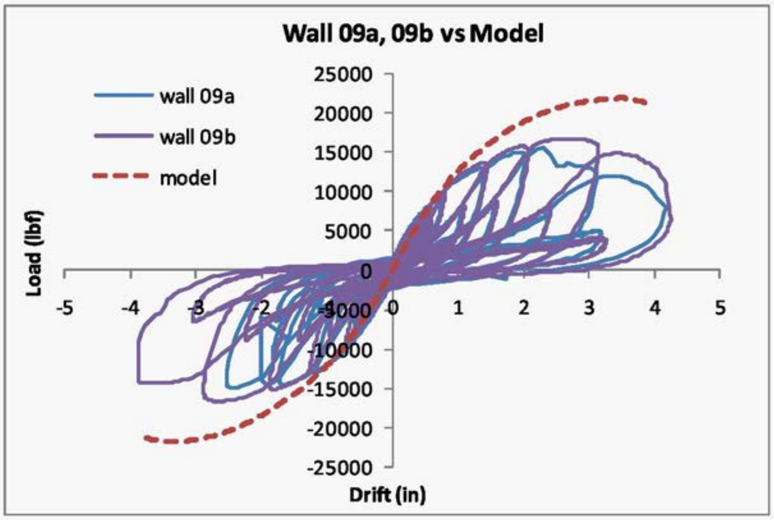


FIGURE 32

WALL #9 – MODEL PREDICTED INTERNAL FORCES vs TEST RESULTS

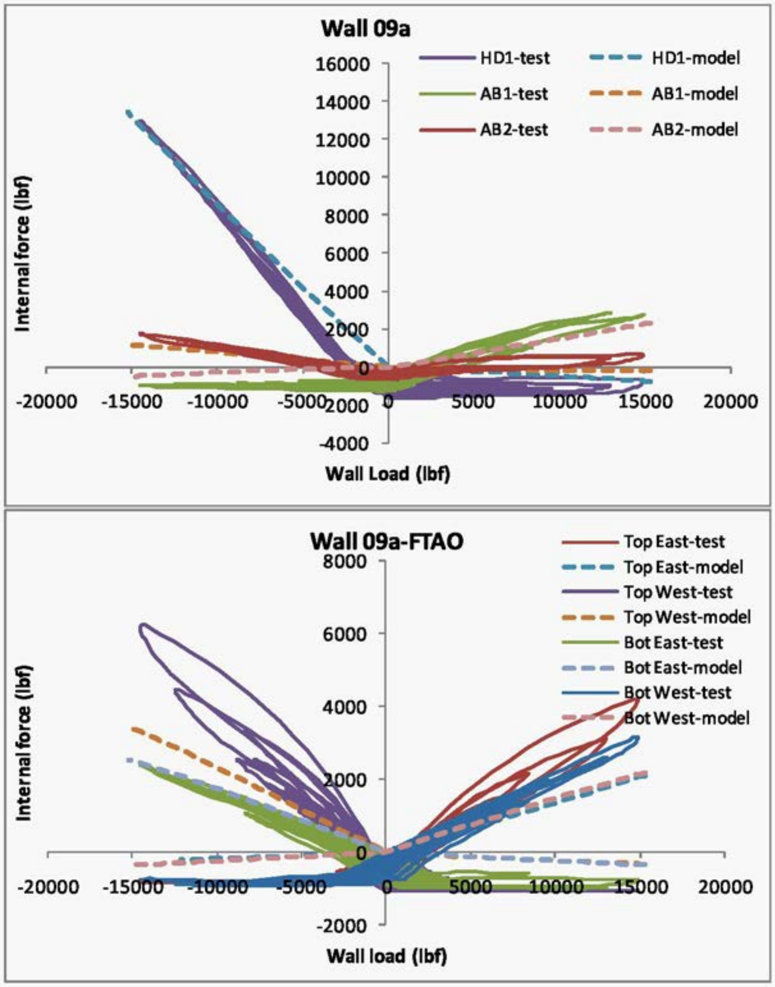


FIGURE 32 **(Continued)**

WALL #9 – MODEL PREDICTED INTERNAL FORCES vs TEST RESULTS

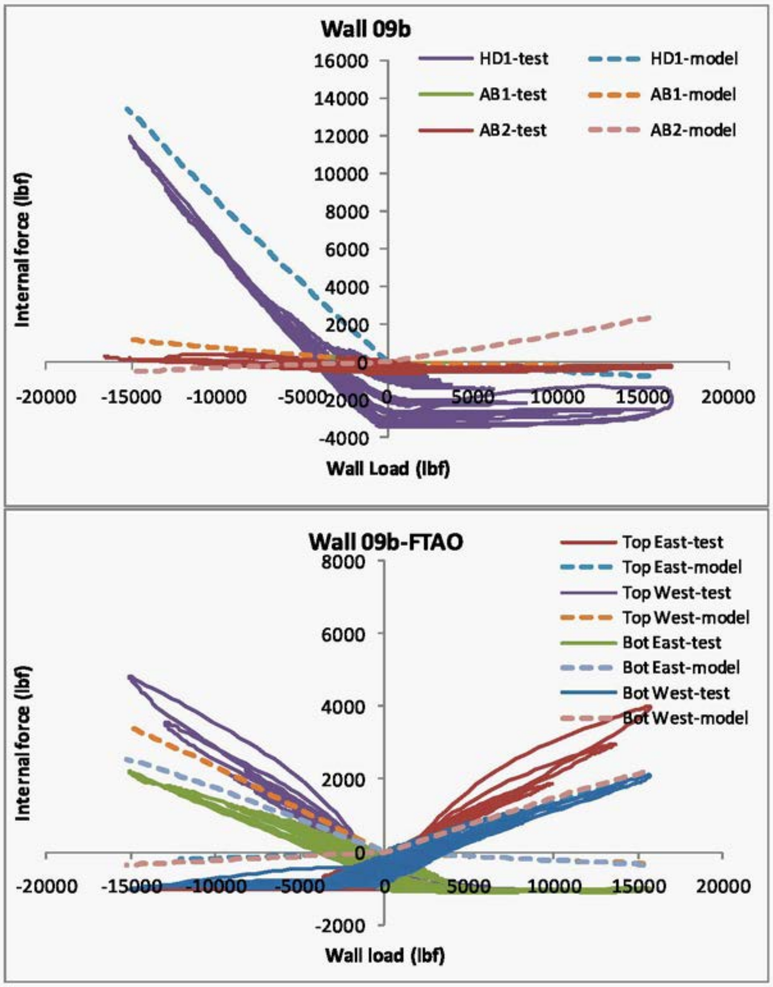


FIGURE 33

WALL #10 – WALL2D MODEL

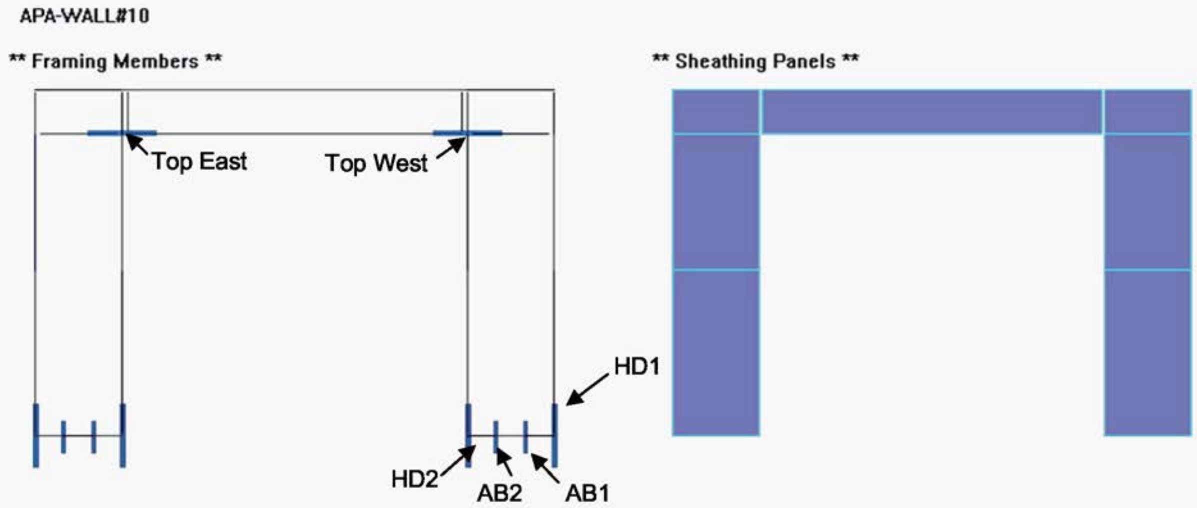


FIGURE 34

WALL #10 – MODEL PREDICTED LOAD-DRIFT CURVES vs TEST RESULTS

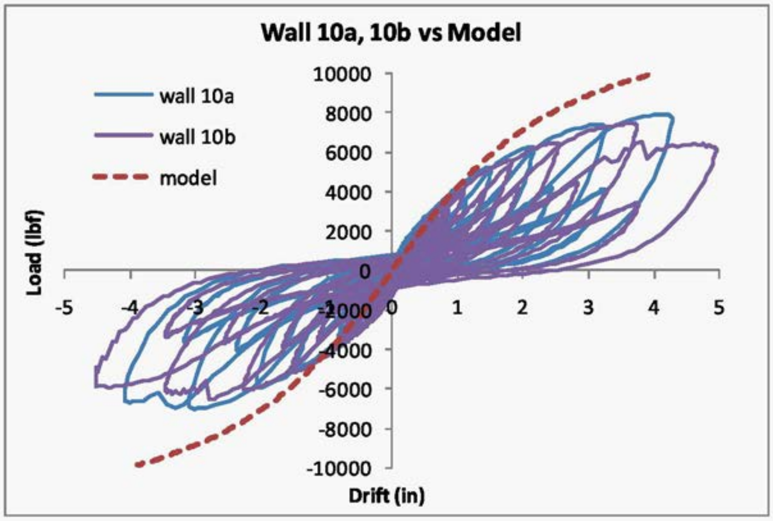


FIGURE 35

WALL #10 – MODEL PREDICTED INTERNAL FORCES vs TEST RESULTS

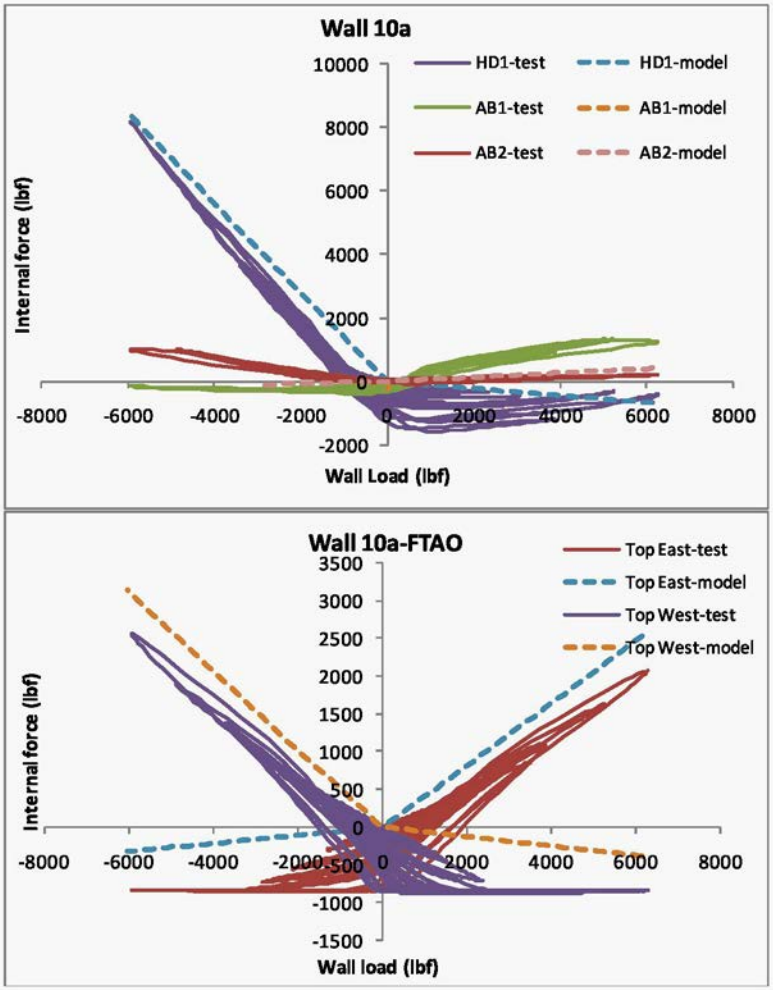


FIGURE 35 (Continued)

WALL #10 – MODEL PREDICTED INTERNAL FORCES vs TEST RESULTS

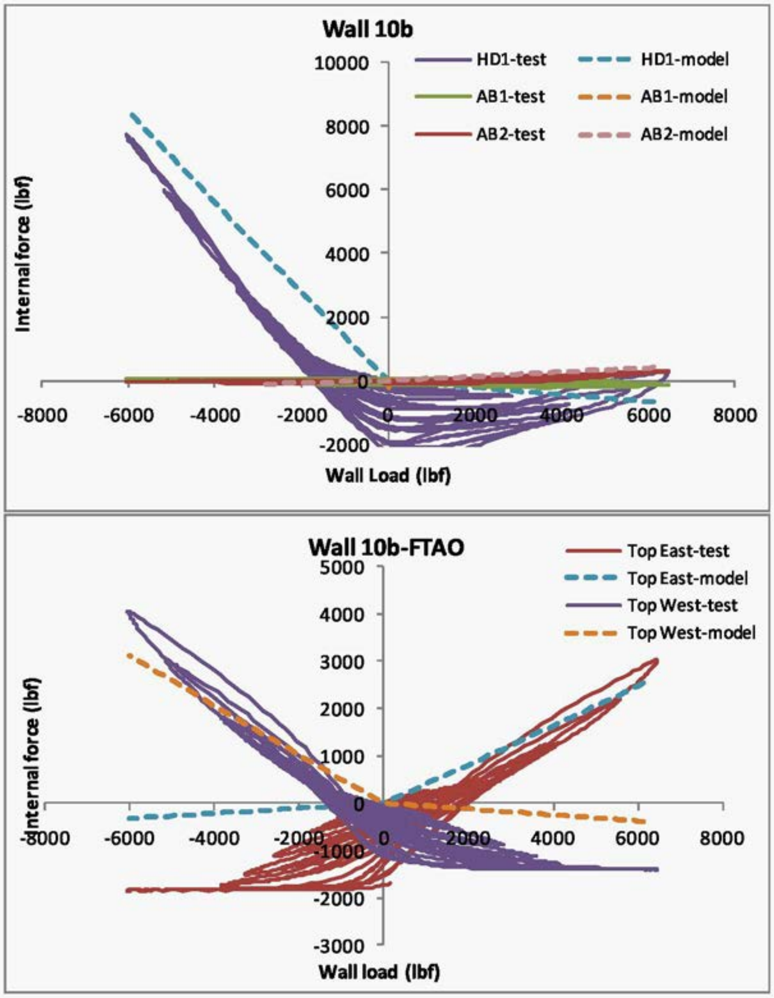


FIGURE 36

WALL #11 – WALL2D MODEL

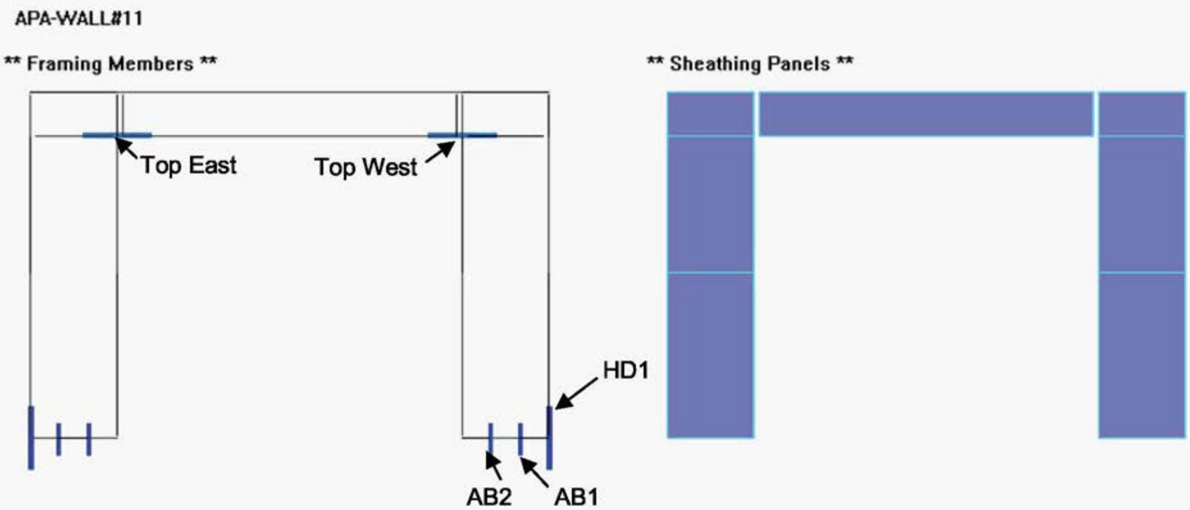


FIGURE 37

WALL #11 – MODEL PREDICTED LOAD-DRIFT CURVES vs TEST RESULTS

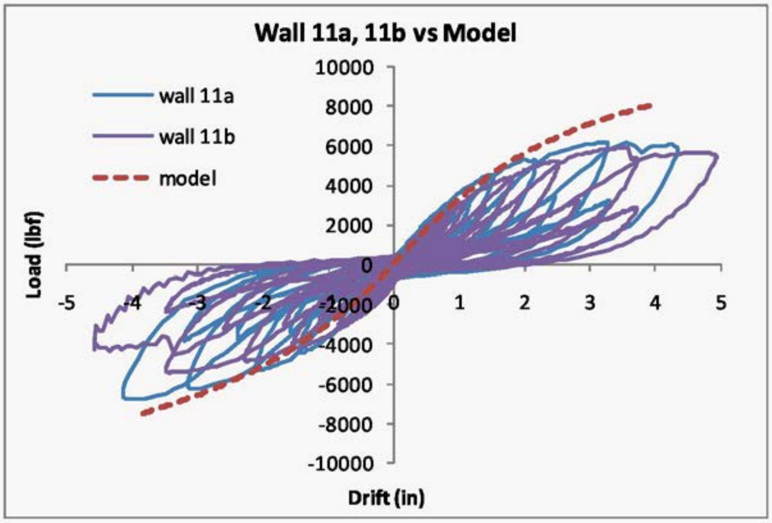


FIGURE 38

WALL #11 – MODEL PREDICTED INTERNAL FORCES vs TEST RESULTS

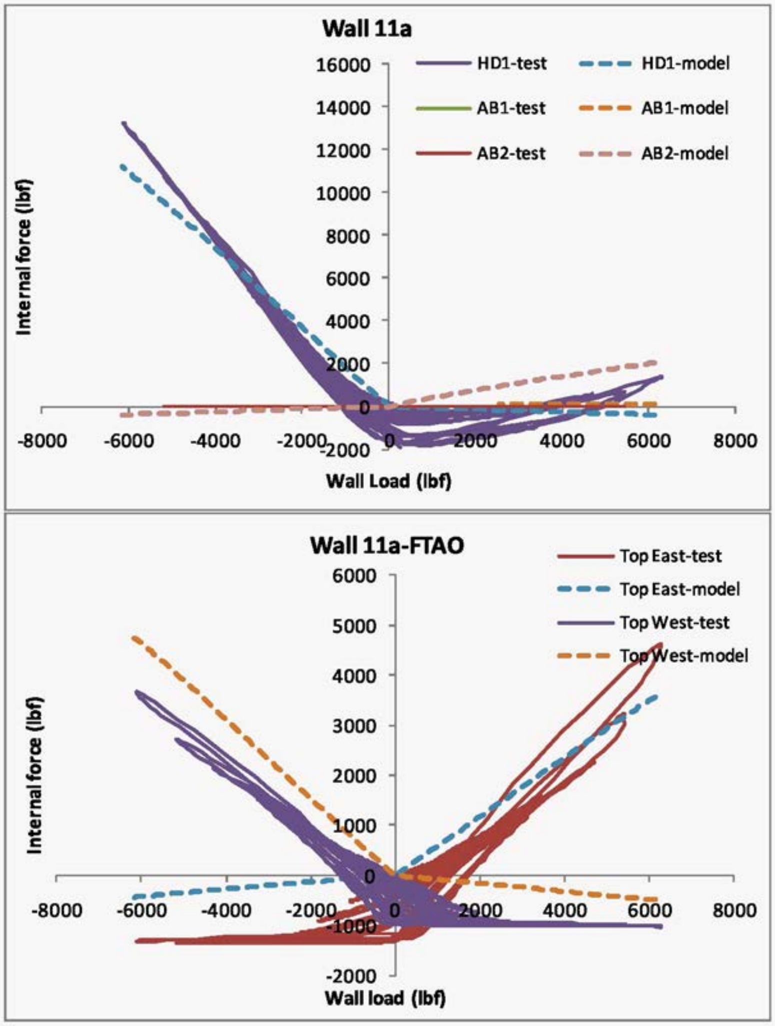
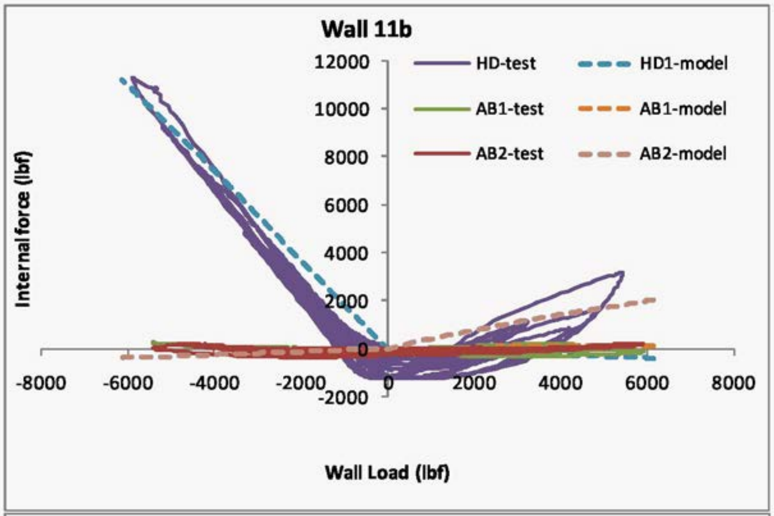


FIGURE 38 (Continued)

WALL #11 – MODEL PREDICTED INTERNAL FORCES vs TEST RESULTS



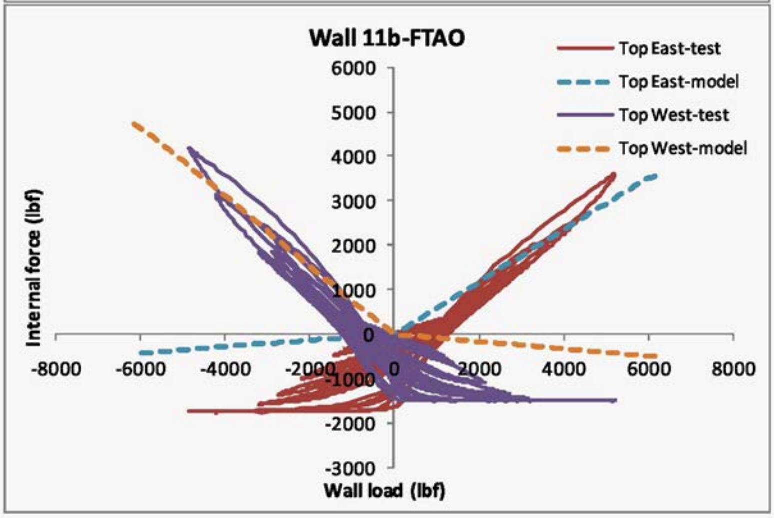


FIGURE 39

WALL #12 – WALL2D MODEL

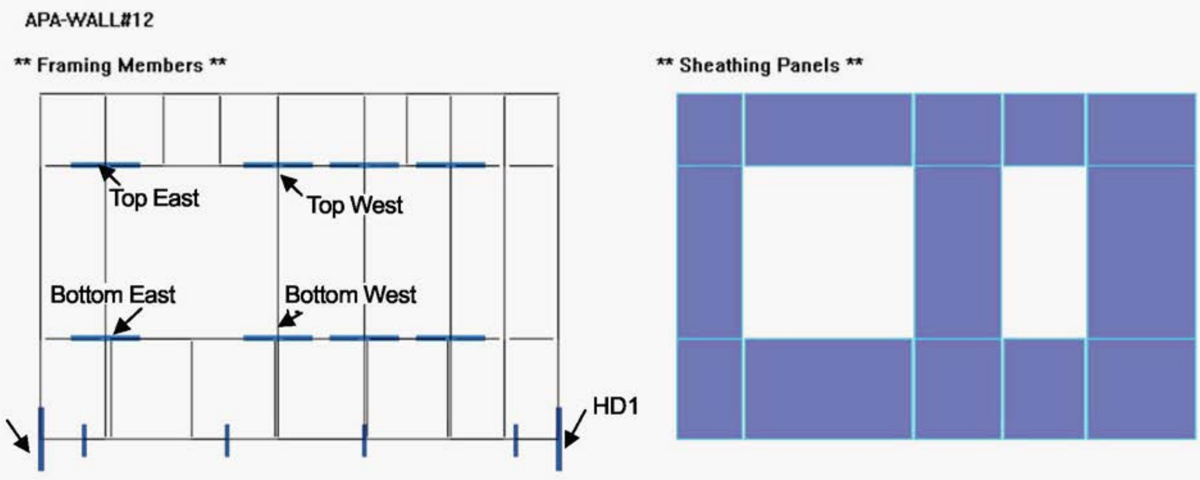


FIGURE 40

WALL #12 – MODEL PREDICTED LOAD-DRIFT CURVES vs TEST RESULTS

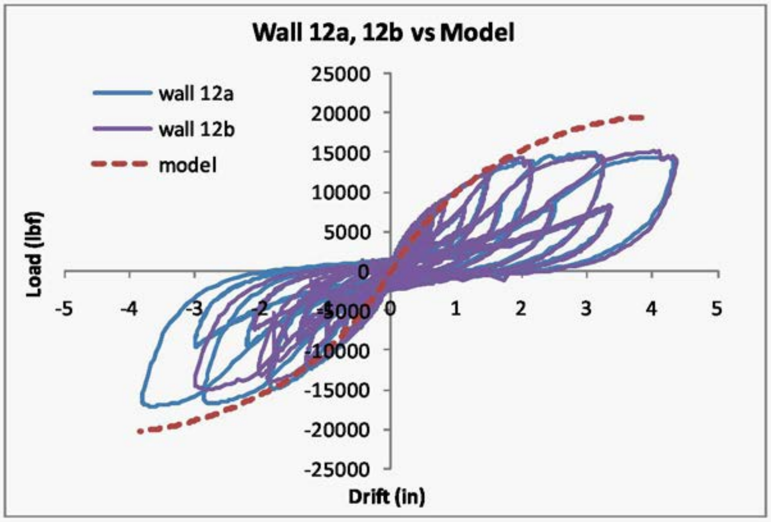


FIGURE 41

WALL #12 – MODEL PREDICTED INTERNAL FORCES vs TEST RESULTS

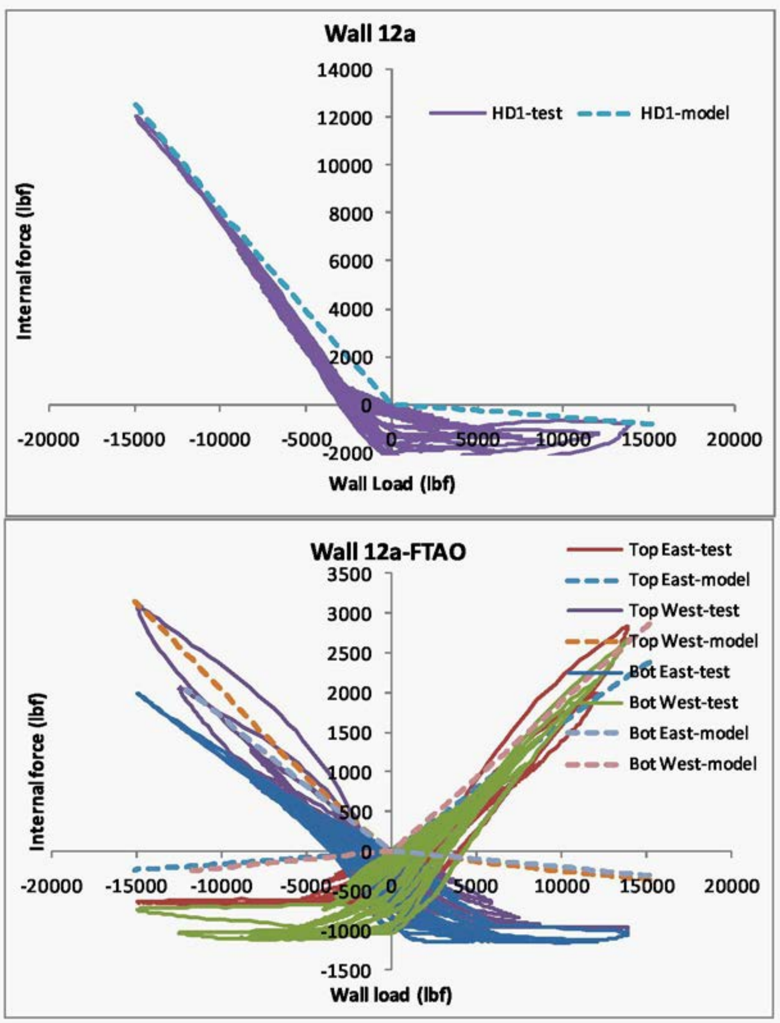
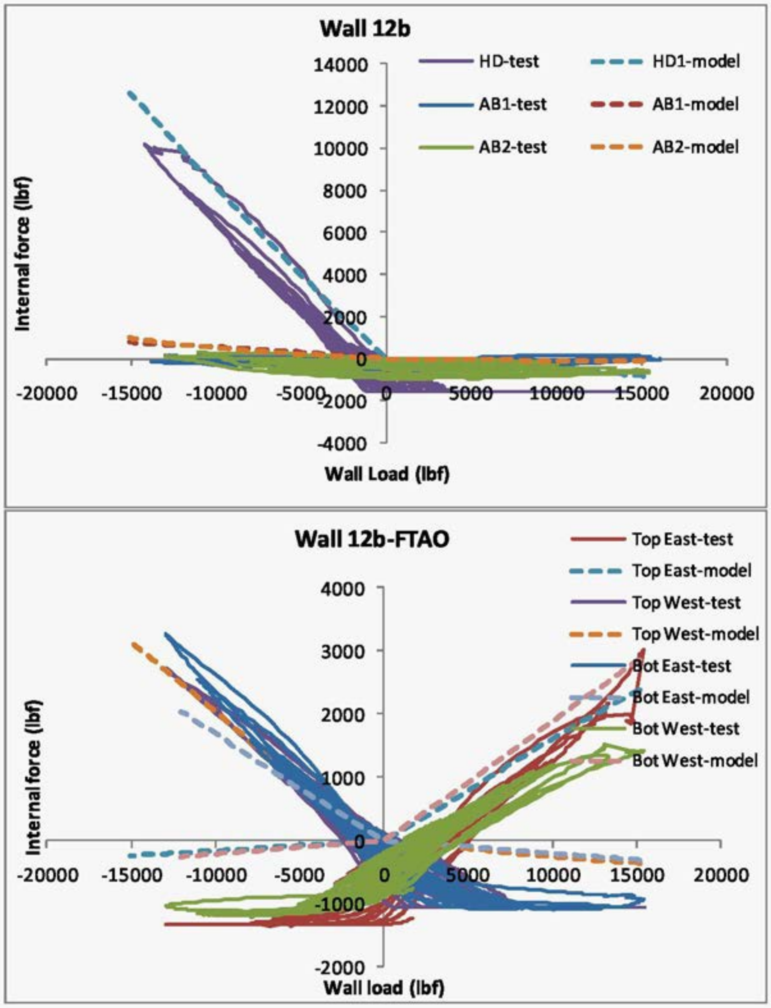


FIGURE 41 **(Continued)**

WALL #12 – MODEL PREDICTED INTERNAL FORCES vs TEST RESULTS



2.6 SUMMARY AND DISCUSSIONS

The wood shear wall model WALL2D was developed to study the behavior of typical wood frame wall systems. Currently, the wall model lacks the ability to consider the degradation in shear walls caused by other failure modes except for the panel-frame nail connections. Such failure modes, including tearing and buckling of the sheathing panels as well as failure of framing members and framing connections, are uncommon in typical non-perforated shear walls under reverse cyclic loading. As observed in the perforated shear wall tests, these failures can indeed occur during loading. With continued application of loads, the wall further weakens and the load path within the wall can alter resulting in the changes of the measured hold down forces and FTAO. To take such behavior into consideration requires additional failure criteria to be developed and new computational schemes to update the system stiffness matrix during the load steps. As the current computer model could not recognize part of the wall has failed, it over predicted the ultimate capacity of these perforated wall systems. Although the WALL2D program is capable of estimating the behavior of shear walls under reversed cyclic loading, for the perforated shear wall cases we only ran the program under monotonic loading schemes. The modeling results showed that when the drifts of the walls went up to 4", the load-drift curves indicated high nonlinearity. In the shear wall tests, at this amount of wall deformation, significant damage in the nail connections, sheathing panels and some framing connections have occurred.

For design purpose, we are interested in the wall response at the wall design capacity. In the U.S., a wall capacity of 870 lbf/ft (12.7 N/mm) is a typical tabulated value based on allowable stress design (Skaggs et al., 2010). Based on this value, the design capacity of the walls considered in this study was established by multiplying this unit shear capacity with the effective length of the wall (i.e., considering the walls with full-height segments). For wall 2 and wall 3, which are perforated walls with only two hold-downs installed on the outermost ends of the walls, their shear wall design capacity is further modified by an additional factor C_0 = 0.93. For the walls with FTAO metal straps, no C_0 adjustment is required. In this study, the model predicted hold-down forces and FTAO were compared against the test results at the wall design capacity level.

Table 1 shows the comparisons between the predicted hold-down forces and the test results. The prediction error range is from –20.6%to +48.7%. Out of the 12 cases, walls 1, 2, and 9 have the prediction errors of -20.6%, +22.5% and +19.0%,respectively. The case of wall 4 has a wide range of measured hold-down forces, which resulted in a prediction error of 48.7%. The rest of the cases had absolute prediction errors range 0.5% to 10.3%.

Table 2 shows the comparisons between the predicted metal strap forces around openings and the test results. The prediction error range is from -38.2% to +44.2%. The case of wall 4 has a wide range of measured FTAO values, which resulted in a prediction error of 44.2%. Given the relatively high variability in the test data and the simplifications/assumptions in the computer model, the predicted errors in most cases seem to be reasonable. In design practice, it is of interest to evaluate the maximum FTAO value for the different walls at the design load capacity level to size the required hardware connection. Therefore, it is of interest to compare the test results with the computer model and simplified analog predictions.

Table 3 shows the maximum FTAO values from the test data in comparison with the values from the computer model and four “rational” design methods (Drag Strut, Cantilevered Beam, Coupled Beam, and Diekmann’s method). The prediction error range of the computer model is -15.4% to +4.3%. The Drag Strut method can both under predict and over predict the maximum FTAO. The Cantilevered Beam, Coupled Beam, and Diekmann’s methods on the other hand seem to be very conservative. Compared to test data and using the Diekmann’s method as a base, a reduction correction factor of the order of 1.2 to 1.3might be considered to account for the contribution of the framing and nail elements within the wall system. Diekmann’s method however is not suitable to predict the FTAO in cases when the wall segment below the opening is not available as in the case of garage door opening.

It should be noted that the FTAO in Wall 6 with the wrapped around sheathing panel cannot be reasonable predicted by the simplified analog even with the correction factor. The limitation of WALL2D model is that it considers only the nonlinearity from panel-frame nail connections and does not consider the degradation caused by the nonlinearity or failure in sheathing panels, framing members and framing connections. Therefore, WALL2D over predicted the load-carrying capacity for some walls where significant nonlinear deformation occurred in the components. The peak load values predicted by WALL2D loaded up to the wall drift of 4" and the associated wall deformations are given in Table 4. Furthermore, in the cases of perforated shear walls, the modulus of elasticity of framing members also plays an important role in the distribution of internal forces in the system.

Although WALL2D model considers the modulus of elasticity values of framing members, it would be more precise if the modulus of elasticity of the framing members used in the wall tests can be non-destructively established apriori for the model verification purpose. The complicated load application system and the force measurement devices also created significant challenges in the modeling process. Overall, the WALL2D predictions of FTAO agreed reasonably well with the test results at the shear wall design level. In future research, parametric studies can be further conducted by this model to study the FTAO of various perforated walls with different opening sizes and different metal hardware at the wall design level, providing more information for rational designs of perforated shear walls. Also, WALL2D can be further extended to address the nonlinearities and failure mechanisms currently ignored in the analysis so that the FTAO behavior of such wall systems can be fully captured under high structural demands (high loads and reversed cycles). With a fine tuned analysis model, studies can also be conducted to consider the FTAO behavior of perforated wall systems under dynamic conditions.

TABLE 1

MODEL PREDICTED HOLD-DOWN FORCES vs TEST RESULTS

	ASD (plf)	Effective Wall Length (ft)	Wall Capacity (lbf)	Hold-Down Forces at Wall Design Capacity	
				Outboard (lbf)	Inboard (lbf)
Wall 1a-test	870	4.5	3915	7881	5313
Wall 1b-test	870	4.5	3915	6637	6216
Wall 1 test avg	870	4.5	3915	7259	5765
Wall 1-model	870	4.5	3915	5765	5673
Error				–20.6%	+1.6%
Wall 2a-test	870	4.5	3631	2216	n/a
Wall 2b-test	870	4.5	3631	3248	n/a
Wall 2 test avg	870	4.5	3631	2732	
Wall 2-model	870	4.5	3631	3347	
Error				+22.5%	
Wall 3a-test	870	4.5	3631	2602	n/a
Wall 3b-test	870	4.5	3631	4090	n/a
Wall 3 test avg	870	4.5	3631	3346	
Wall 3-model	870	4.5	3631	3202	
Error				–4.3%	
Wall 4a-test	870	4.5	3915	1140	n/a
Wall 4b-test	870	4.5	3915	3674	n/a
Wall 4c-test	870	4.5	3915	1336	n/a
Wall 4d-test	870	4.5	3915	1598	n/a
Wall 4 test avg	870	4.5	3915	1937	
Wall 4 model	870	4.5	3915	2882	
Error				48.7%	
Wall 5b-test	870	4.5	3915	5216	n/a
Wall 5c-test	870	4.5	3915	4795	n/a
Wall 5d-test	870	4.5	3915	4413	n/a
Wall 5 test avg	870	4.5	3915	4808	
Wall 5 model	870	4.5	3915	4418	
Error				–8.1%	
Wall 6a-test	870	4.5	3915	1573	n/a
Wall 6b-test	870	4.5	3915	1285	n/a
Wall 6 test avg	870	4.5	3915	1429	
Wall 6 model	870	4.5	3915	1529	
Error				+7.0%	
Wall 7a-test	870	8	6960	6024	3677
Wall 7b-test	870	8	6960	6577	3744
Wall 7 test avg	870	8	6960	6301	3761
Wall 7 model	870	8	6960	6093	5108
Error				–10.3%	+35.8%

TABLE 1 (Continued)

MODEL PREDICTED HOLD-DOWN FORCES vs TEST RESULTS

	ASD (plf)	Effective Wall Length (ft)	Wall Capacity (lbf)	Hold-Down Forces at Wall Design Capacity	
				Outboard (lbf)	Inboard (lbf)
Wall 8a-test	870	8	6960	4805	n/a
Wall 8b-test	870	8	6960	5548	n/a
Wall 8 test avg	870	8	6960	5176	
Wall 8 model	870	8	6960	5149	
Error				0.5%	
Wall 9a-test	870	8	6960	4679	n/a
Wall 9b-test	870	8	6960	5212	n/a
Wall 9 test avg	870	8	6960	4945	
Wall 9-model	870	8	6960	5887	
Error				+19.0%	
Wall 10a-test	870	4	3480	5311	5690
Wall 10b-test	870	4	3480	4252	3731
Wall 10 test avg	870	4	3480	4781	4710
Wall 10 model	870	4	3480	4870	4138
Error				+1.9%	–12.1%
Wall 11a-test	870	4	3480	6449	n/a
Wall 11b-test	870	4	3480	5843	n/a
Wall 11 test avg	870	4	3480	6146	
Wall 11 model	870	4	3480	6441	
Error				+4.8%	
Wall 12a-test	870	6	5220	2856	n/a
Wall 12b-test	870	6	5220	3458	n/a
Wall 12 test avg	870	6	5220	3157	
Wall 12 model	870	6	5220	3238	
Error				+2.6%	

TABLE 2

MODEL PREDICTED FTAO vs TEST RESULTS

Wall	ASD (plf)	Effective Wall Length (ft)	Wall Capacity (lbf)	FTAO at wall design capacity	
				Top (lbf)	Bottom (lbf)
Wall 4a-test	870	4.5	3915	687	1485
Wall 4b-test	870	4.5	3915	560	1477
Wall 4c-test	870	4.5	3915	668	1316
Wall 4d-test	870	4.5	3915	1006	1665
Wall 4 test avg	870	4.5	3915	730	1486
Wall 4 model	870	4.5	3915	1053	1401
Error				44.2%	–5.7%
Wall 5b-test	870	4.5	3915	1883	1809
Wall 5c-test	870	4.5	3915	1611	1744
Wall 5d-test	870	4.5	3915	1633	2307
Wall 5 test avg	870	4.5	3915	1709	1953
Wall 5 model	870	4.5	3915	2038	1946
Error				19.2%	–0.4%
Wall 6a-test	870	4.5	3915	421	477
Wall 6b-test	870	4.5	3915	609	614
Wall 6 test avg	870	4.5	3915	515	546
Wall 6 model	870	4.5	3915	462	337
Error				–10.3%	–38.2%
Wall 8a-test	870	8	6960	985	1347
Wall 8b-test	870	8	6960	1493	1079
Wall 8 test avg	870	8	6960	1239	1213
Wall 8 model	870	8	6960	1292	1047
Error				4.3%	–13.7%
Wall 9a-test	870	8	6960	1675	1653
Wall 9b-test	870	8	6960	1671	1594
Wall 9 test avg	870	8	6960	1673	1623
Wall 9-model	870	8	6960	1627	1228
Error				–2.7%	–24.3%
Wall 10a-test	870	4	3480	1580	n/a
Wall 10b-test	870	4	3480	2002	n/a
Wall 10 test avg	870	4	3480	1791	n/a
Wall 10 model	870	4	3480	1787	n/a
Error				–0.2%	n/a
Wall 11a-test	870	4	3480	2466	n/a
Wall 11b-test	870	4	3480	3062	n/a
Wall 11 test avg	870	4	3480	2764	n/a
Wall 11 model	870	4	3480	2700	n/a
Error				–2.3%	n/a

TABLE 2 (Continued)

MODEL PREDICTED FTAO vs TEST RESULTS

Wall	ASD (plf)	Effective Wall Length (ft)	Wall Capacity (lbf)	FTAO at wall design capacity	
				Top (lbf)	Bottom (lbf)
Wall 12a-test	870	6	5220	807	1163
Wall 12b-test	870	6	5220	1083	1002
Wall 12 test avg	870	6	5220	945	1082
Wall 12 model	870	6	5220	824	966
Error				–12.8%	–10.7%

TABLE 3

COMPUTER MODEL AND SIMPLIFIED ANALOG PREDICTED MAXIMUM FTAO vs TEST RESULTS

Wall	Max FTAO at Wall Capacity (lbf)					
	Test Results	Computer Model	Drag Strut	Cantilever	Couple Beam	Diekmann
4	1486	1401 –5.7%	1223 –17.7%	4474 201.1%	2796 88.2%	1958 31.7%
5	1953	2038 4.4%	1223 –37.4%	6152 215.0%	3845 96.9%	3263 67.1%
6	546	462 –15.4%	1223 124.1%	4474 719.5%	2796 412.2%	3263 497.5%
8	1239	1292 4.3%	1160 –6.4%	7954 542.0%	2651 114.0%	1856 49.8%
9	1673	1627 –2.7%	1160 –30.7%	10937 553.7%	3646 117.9%	3093 84.9%
10	1791	1787 –0.2%	1160 –35.2%	– –	– –	9280 418.1%
11	2764	2700 –2.3%	1160 –58.0%	– –	– –	9280 235.7%
12	1082	966 –10.7%	– –	– –	– –	– –

TABLE 4

COMPUTER MODEL PREDICTED PEAK LOADS AND THE CORRESPONDING WALL DRIFTS

Wall	Computer Model Peak load (lbf)	Wall drift at peak load (in.)
1	8029	4.0
2	14991	4.0
3	17049	4.0
4	18081	2.85
5	14017	4.0
6	21973	2.98
7	17761	3.11
8	25758	3.43
9	21823	3.50
10	9881	4.0
11	8018	4.0
12	19468	4.0

2.6 REFERENCES

Canadian Standard Association (CSA). 2001. *Engineering Design in Wood.* CSA, Toronto, On, Canada.

Diekmann, E.F. 1997. "Diaphragms and Shearwalls" in: *Wood Engineering and Construction Handbook.* 3rd ed. K. F. Faherty and T. G. Williamson, eds. McGraw-Hill, New York. pp. 8.47–8.79.

Diekmann, E. F. 2005. "Discussion and Closure of Design of Wood Structural Panel Shear Walls with Openings: A Comparison of Methods." *Wood Design Focus.* (15)2:14–15.

Foschi, O. R. Li, M. and Lam, F. 2010. "Modeling Hysteretic Behavior of Panel-Frame Nail Connections in Wood Construction." *ASCE Journal of Structural Engineering* (under review).

Intel Corporation. 2005. *Intel® Fortran Compiler Integration for Microsoft Visual Studio.* Version 10.1.4160.2005.

Kolba, A. 2000. *The Behavior of Wood Shear Walls Designed Using Diekmann's Method and Subjected to Static In-Plane Loading.* Thesis submitted in partial fulfillment for the degree of Doctor of Philosophy. Marquette University.

Lam, F. 2010. *Review of Common Methods to Estimate Force Transfer around Openings for Wood Frame Shearwalls.* Report prepared for *APA - The Engineered Wood Association.* University of B.C. Canada

Li, M., Foschi, R. 0. and Lam, F. 2011. "Modeling Hysteretic Behavior of Wood Shear Walls with a Protocol-Independent Nail Connection Algorithm." *ASCE Journal of Structural Engineering* (under review).

Martin, Z. 2005. "Design of Wood Structural Panel Shear Walls with Openings: A Comparison of Methods." Wood *DesignFocus.* (15)1:18–20.

Robertson, A. A. 2004. *Comparison of Methodologies for Designing of Force Transfer around Openings in Plywood Shear Walls.* Presentation in the 2004 Forest Products Society Meeting on Woodframe Housing Durability and Disaster Issues. Session 111: Disaster Mitigation. Las Vegas, Nevada, USA.

Simpson Strong-Ties Co., Inc. 2010. http://www.strongtie.com/product/alpha_list.html.

Skaggs, T., Yeh, B.J., Lam, F., Rammer, D. and Wacker, J. 2010. *Full-scale Shear Wall Tests for Force Transfer around Openings.* CIB-W18/43–15-3, Nelson, New Zealand.

Thomas, W. H. 2003. "Poisson's Ratios of an Oriented Strand Board." *Wood Science and Technology,* 37:259–268.

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