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Shear Wall Lumber Framing: Double 2x's vs. Single 3x's at Adjoining Panel Edges

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Double 2x's vs. Single 3x's
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SUMMARY

The purpose of this study was to examine the effect of 3x framing versus stitch-nailed double 2x framing at adjoining panel edges on the performance of wood structural panel shear walls. After the 1994 Northridge earthquake, model codes required 3x lumber framing at adjoining panel edges in higher seismic zones for shear walls with an allowable capacity greater than 350 plf. The 3x lumber framing code provision provides a larger surface for nailing than does a single 2x, helps prevent splitting of the framing, and allows for increased edge distances in both the wood structural panels and the wood framing. The two 2x's stitch-nailed together provides the nailing surface benefits of the single 3x.

In this study, the double 2x's were stitch-nailed together based on an engineered connection design to transfer the design shear from one 2x to the next. A total of eight 8-ft x 8-ft shear walls were tested using the CUREE (Krawinkler, et al., 2000) cyclic load protocol. Four shear walls were constructed to have an allowable design shear capacity of 350 pounds per lineal foot (plf) to represent the lower bound of the 3x framing requirement, and four shear walls were constructed to have an 870 plf allowable capacity to represent the upper bound of the shear wall allowable capacity matrix. Results from cyclic shear wall testing show that the shear walls with double 2x's stitch-nailed together perform about the same as those with a single 3x by all measures, except the shear walls with double 2x framing had increased displacement capacity and ductility, which is a desirable characteristic for seismic performance.

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

Table of Contents

1 Background and Objective

After the 1994 Northridge earthquake, model codes required 3x lumber framing at adjoining panel edges in higher seismic zones for shear walls with an allowable capacity greater than 350 plf. The 3x lumber framing code provision provides a larger surface for nailing than does a single 2x, helps prevent splitting of the framing, and allows for increased edge distances in both the wood structural panels and the wood framing. The two 2x's stitch-nailed together provides the nailing surface benefits of the single 3x.

The purpose of this study was to examine the effect of 3x framing versus stitch-nailed double 2x framing at adjoining panel edges on the performance of wood structural panel shear walls.

2 Introduction

In this study, the double 2x's were stitch-nailed together based on an engineered connection design to transfer the design shear from one 2x to the next. A total of eight, 8-ft x 8-ft, shear walls were tested using the CUREE (Krawinkler, et al., 2000) cyclic load protocol. Four shear walls were constructed to have an allowable design shear capacity of 350 pounds per lineal foot (plf) to represent the lower bound of the 3x framing requirement, and four shear walls were constructed to have an 870 plf allowable capacity to represent the upper bound of the shear wall allowable capacity matrix.

3 Materials

3.1 Framing

All framing was No. 2 Douglas-fir (DF) kiln dried lumber. The framing size and layout for all the walls tested is shown in Figure 1.

3.2 Wall Sheathing

For the 350 plf walls (walls 1-4), 7/16-inch APA Rated Sheathing oriented strand board (OSB) with a span rating of 24/16 Exposure 1, purchased on the open market, was used. For the 870 plf walls (walls 5-8), 19/32-inch APA Rated Sheathing oriented strand board (OSB) with a span rating of 40/20 Exposure 1 purchased on the open market, was used.

3.3 Fasteners

For the 350 plf walls (walls 1-4), nails used for attaching wood structural panel sheathing to framing were 8d common (0.131-inch diameter x 2-1/2 inches long). For the 870 plf walls (walls 5-8), nails used for attaching wood structural panel sheathing to framing were 10d common (0.148-inch diameter x 3 inches long). Nails used for stitch nailing the double 2x4 studs were 10d common (0.148-inch x 3-inch). 16d sinkers (0.148-inch x 3-1/4-inch) were used to end nail plates to studs.

3.4 Hold-downs

Commercially available hold-downs were used and attached with lag screws that accompanied the hold-downs. Walls 1-4 had a hold down device with a 3610-lb allowable tension load and walls 5-8 had a hold down device with a 6730-lb allowable tension load.

4 Test Specimens

A summary of the test specimens is given in Table 1. The framing details were described in Section 2 of this report and by Figure 1. The stitch nail calculations are shown in Figure 2, along with the calculated nail spacing schedule.

Table 1. Summary of test specimens

Test Purpose	Wall	Description	Number of Specimens	Construction		
				OSB Thickness	Edge Nailing	ASD Capacity (plf)
Lower bound	1,2	3x	2	7/16"	8d @ 4" o.c.	350
	3,4	2x - stitch(1)	2			
Upper bound	5,6	3x	2	19/32"	10d @ 2" o.c.	870
	7,8	2x - stitch(2)	2			

Notes:

(1) 14, 10d common nails needed to transfer shear

(2) 35, 10d common nails needed to transfer shear

5 Test Set-up and Procedure

5.1 Boundary Conditions

The OSB sheathing was free to rotate in that the OSB sheathing was bearing on neither the “foundation” frame nor the load beam during the testing.

5.2 Instrumentation

Four linear potentiometer (LP) devices were used to measure displacement. These were placed to record:

- Crushing and uplift at double end studs (2 LP’s total, one on each end stud).
- Sliding of the sill plate.
- Global lateral displacement. This was collected at the upper top plate at the end away from the load head.

The applied load was measured with a load cell located between the MTS hydraulic actuator and the load head.

Displacement was applied to the wall at a rate of 0.5 Hz and data was recorded at 500 Hz. The data is over-sampled and averaged so that 100 data points per cycle are reported.

5.3 Cyclic Load Protocol

The displacement protocol for these tests followed the CUREE load protocol (Krawinkler, et. al. 2000). The delta, to which CUREE protocol displacement cycles are correlated, was set at 2.4 in. based on experience. An additional set of cycles was added so that the maximum displacement was 4.8 in. or 200% of delta.

6 Test Results

A summary of the test results is shown in Table 2. Hysteresis loops are shown in Appendix A. Backbone curves of the 350 plf and 870 plf walls are shown in Figures 3 and 4, respectively. Wall 2 had an end post framing failure (see Appendix B, Figure B7), which is represented in Figure 3 where the positive excursion backbone curve deviates from the group. Wall 6 also had an end post framing failure, which is represented in Figure 4 where the negative excursion backbone curve deviates from the group (near peak load capacity). Data from Wall test 2 and 6 is still used because the end post (a stitch-nailed double 2x for Wall 2 and a single 4x4 for Wall 6) can be shown to be adequate at the allowable stress design level of the shear wall. Typical controlling failure modes were nails yielding, tearing from panel edges and nail head pull-through. No difference in controlling failure mode was observed between any test. Photos of these typical failure modes are shown in Appendix B. Energy dissipation curves of the 350 plf and 870 plf walls are shown in Figures 5 and 6, respectively.

7 Discussion

For perspective it is noted that differences in response parameters shown in Table 2 between identical specimens in this test program range from 0-17% (e.g. the displacement at allowable design load between Walls 5 and 6, identically constructed walls, is 15%). Other cyclic test wood shear wall studies have shown differences between matched specimens to range up to near 20% (Pardoen et al., 2002; COLA-UCI, 2001; Salenikovich and Dolan, 2003). It should also be noted that these large differences (above 10%) between identical specimens are most often associated with measures of deflection. Measures of load, including ultimate capacity, usually show less than 10% difference between identical specimens.

The only measured response difference between the variable (stitch-nailed double 2x vs. single 3x center stud) that is greater than 15% is the displacement at ultimate load. The only calculated response difference between the variable that is greater then 15% is the ductility. The walls with stitch-nailed double 2x center studs had increased displacement at its ultimate load capacity and increased ductility compared to the shear wall with a single 3x center stud. This increased deformation capacity is likely due to the introduced shear plane and subsequent slip between the double 2x center stud at loads above the allowable design level.

All other measured and calculated response parameter (ultimate load capacity, stiffness and displacement at allowable design load, overstrength, and energy dissipation) differences between the stitch-nailed double 2x vs. single 3x center stud are on the order of difference between identical specimens, thus such differences are not considered significant.

8 Conclusion

Results from cyclic shear wall testing show that the shear walls with double 2x's stitch-nailed together perform about the same as those with a single 3x by all measures, except the shear walls with double 2x framing had increased displacement capacity and ductility.

Other engineered wood connection designs per the 2001 National Design Specification (NDS) for Wood Construction to connect double 2x framing would be expected to perform similarly. However a bolted connection, like a shear wall with a bolted hold down device would be expected to have more slip than a nailed or lag screw connection, since bolt holes are typically over-drilled to facilitate installation.

References

COLA-UCI, 2001. Report of a Testing Program of Light-Framed Walls with Wood-Sheathed Shear Panels. Final Report to the City of Los Angeles Department of Building Safety by SEAOSC, COLA-UCI Light Frame Test Committee, and the Dept. of Civil and Environmental Engineering at the University of California, Irvine. December, 2001.

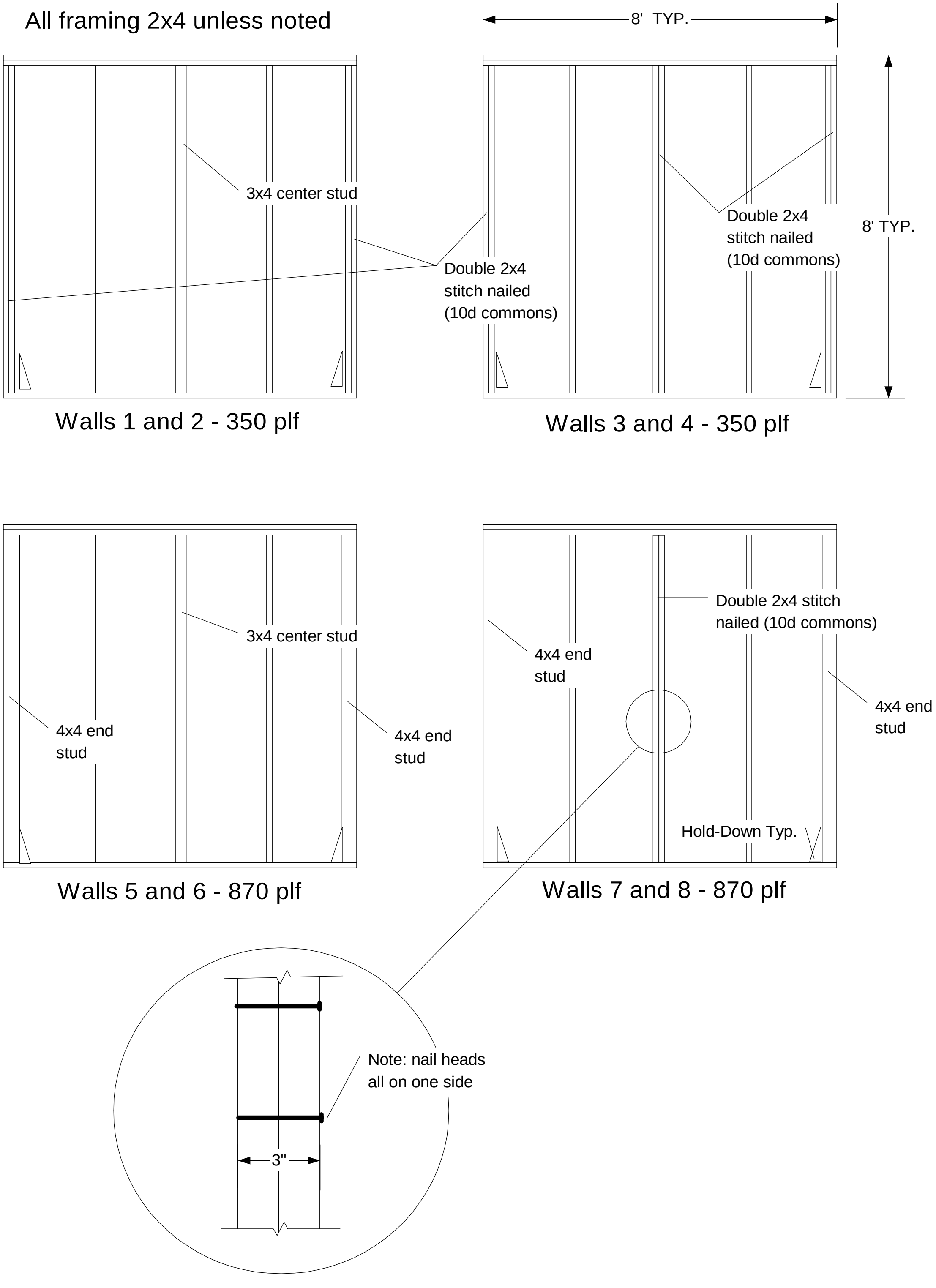
Krawinkler, H. , F. Parisi, L. Ibarra, A. Ayoub, and R. Medina, 2000. *Development of a Testing Protocol for Woodframe Structures*, Report W-02 covering Task 1.3.2, CUREE/Caltech Woodframe Project. Consortium of Universities for Research in Earthquake Engineering (CUREE), Richmond, CA.

NDS, 2001. National Design Specification for Wood Construction. American Forest and Paper Association, Washington, D.C.

Pardoen, G.C., Kazanjy, R.P., Hamilton, C.H., Waltman, A., Freund, E. 2002. *Testing and Analysis of One-Story and Two-Story Shear Walls Under Cyclic Loading*. University of California Irvine. Draft for CUREE task 1.4.4.

Salenikovich, A.J., and Dolan J.D. 2003. *The racking performance of shear walls with various aspect ratios, parts 1 and 2.* Forest Products Journal. In press.

Figure 1. Framing details



Walls 1 and 2 - 350 plf

Walls 3 and 4 - 350 plf

Walls 5 and 6 - 870 plf

Walls 7 and 8 - 870 plf

Typical Stitch-Nailed Doubled 2x4 Studs

Stitch nailing calculations

1. Single fastener allowable lateral design value, Z:

$Z = 118\,\text{lbf}$ From Table 11N of the 2001 NDS. Nominal lateral design value for one 10d common (0.148" x 3.0") nail in single shear when both members are 1.5" thick Douglas fir. Note: nail penetration of 1.5" exceeds 10x the nail diameter, thus footnote 3 of table 11N is not applicable.

$C_D = 1.6$ From Table 2.3.2 of the 2001 NDS. Load duration factor to adjust nominal fastener design value to a short term load duration for wind or earthquake.

$Z_{allowable} = Z \cdot C_D$ $Z_{allowable} = 188.8\,\text{lbf}$ Allowable single fastener design value for described application

2. Load to be transferred between 2x members, V:

$v_{350} = 350\,\dfrac{\text{lbf}}{\text{ft}}$ Allowable design shear capacity of walls 1-4

$v_{870} = 870\,\dfrac{\text{lbf}}{\text{ft}}$ Allowable design shear capacity of walls 5-8

$L = 91.5\,\text{in}$ Length of framing member

$V_{350} = v_{350} \cdot L$ $V_{350} = 2669\,\text{lbf}$ Total load to be transferred between 2x framing members for the 350 plf walls (walls 1-4)

$V_{870} = v_{870} \cdot L$ $V_{870} = 6634\,\text{lbf}$ Total load to be transferred between 2x framing members for the 870 plf walls (walls 5-8)

3. Determine number of nails needed to transfer load, N:

$N_{350} = \dfrac{V_{350}}{Z_{allowable}}$ $N_{350} = 14.1$ Number of nails needed to transfer load between 2x framing members for the 350 plf walls

$N_{870} = \dfrac{V_{870}}{Z_{allowable}}$ $N_{870} = 35.1$ Number of nails needed to transfer load between 2x framing members for the 870 plf walls

4. Calculate uniform nail spacing, S (assuming 2 parallel rows of nails):

$D = 0.148\,\text{in}$ Nail diameter

$S_{350} = \left[\dfrac{L - (2 \cdot 7 \cdot D)}{N_{350}}\right] \cdot 2$ $S_{350} = 12.7\,\text{in}$ Nail spacing assuming 2 parallel rows of nails. 7D end distance is assumed from end of framing to first nail.

For testing: 14 nails total, two parallel rows, and spacing between nails in a row = 12.75"

$S_{870} = \left[\dfrac{L - (2 \cdot 7 \cdot D)}{N_{870}}\right] \cdot 2$ $S_{870} = 5.1\,\text{in}$ Nail spacing assuming 2 parallel rows of nails. 7D end distance is assumed from end of framing to first nail.

For testing: 35 nails total, two parallel rows, and spacing between nails in a rows = 5.25"

Table 2. Summary of test results

Design Load		Center Stud	#	Design						SLS averages				SLS/Design			
				Load	Disp.	K^3	Load	Disp.	K^3	Load	Disp.	Load	Disp.	Load	Disp.	Load	Disp.
(plf)	(lb)			(lb)	(in.)	(k/in.)	(lb)	(in.)	(k/in.)	(lb)	(in.)	(lb)	(in.)	Ω^1	μ^2	Ω^1	μ^2
350	2800	3x	1	2800	0.124	23	2800	0.13	21	7491	1.96	7255	1.78	2.68	16	2.59	14
			2	2800	0.139	20				7019	1.61			2.51	12		
		2-2x	3	2800	0.152	18	2800	0.15	19	6999	2.79	6850	2.55	2.50	18	2.45	17
			4	2800	0.149	19				6701	2.32			2.39	16		
		% diff. between double 2x and 3x						15%	-13%	-	-	-6%	43%	-	-	-6%	24%
870	6960	3x	5	6960	0.245	28	6960	0.26	27	16158	2.66	16206	2.68	2.32	11	2.33	10
			6	6960	0.282	25				16254	2.69			2.34	10		
		2-2x	7	6960	0.282	25	6960	0.28	25	17856	3.33	17639	3.37	2.57	12	2.53	12
			8	6960	0.278	25				17421	3.40			2.50	12		
		% diff. between double 2x and 3x						6%	-6%	-	-	9%	26%	-	-	9%	18%

1. Ω = SLS load/Design load. A measure of overstrength.
2. μ = SLS deflection/Design deflection. A measure of ductility.
3. K = stiffness = load/displacement.

Figure 3. Backbone curves for walls 1-4 (350 plf walls)

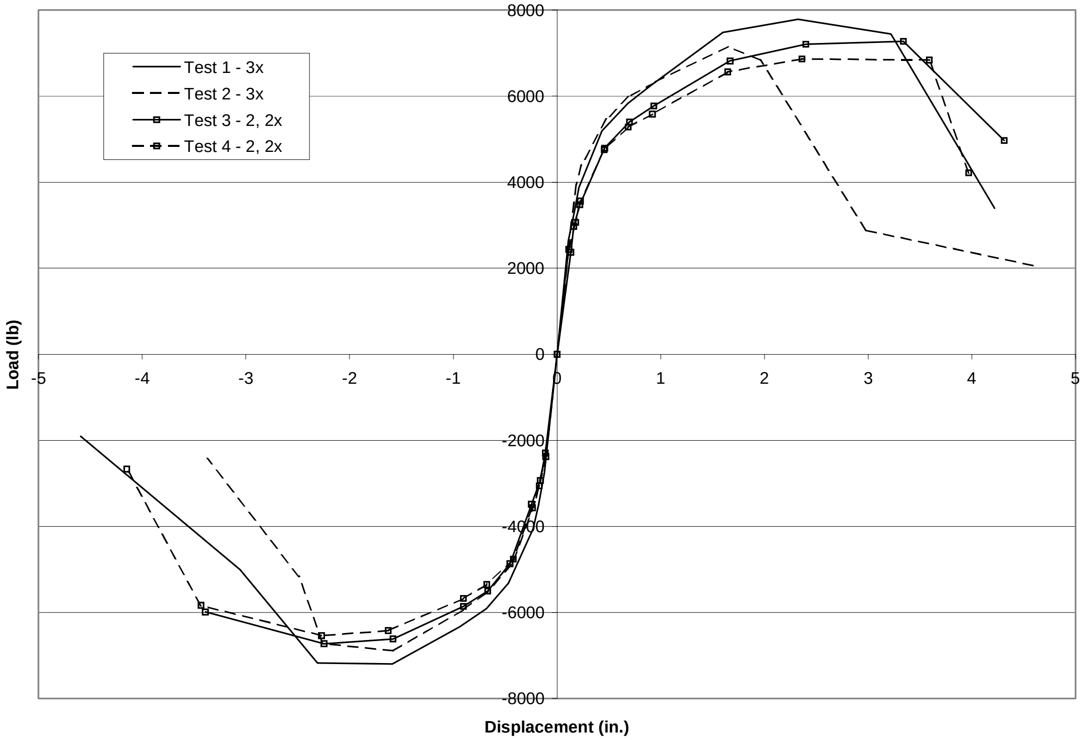


Figure 4. Backbone curves for walls 5-8 (870 plf walls)

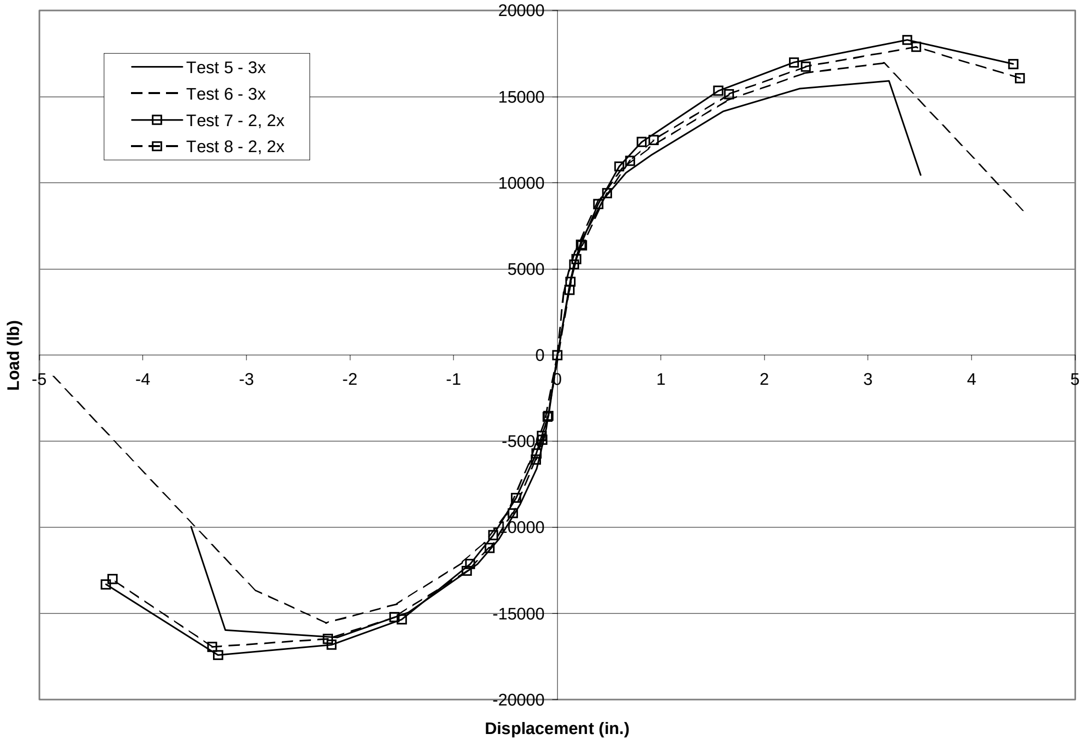


Figure 5. Energy dissipation curves for walls 1-4 (350 plf walls)

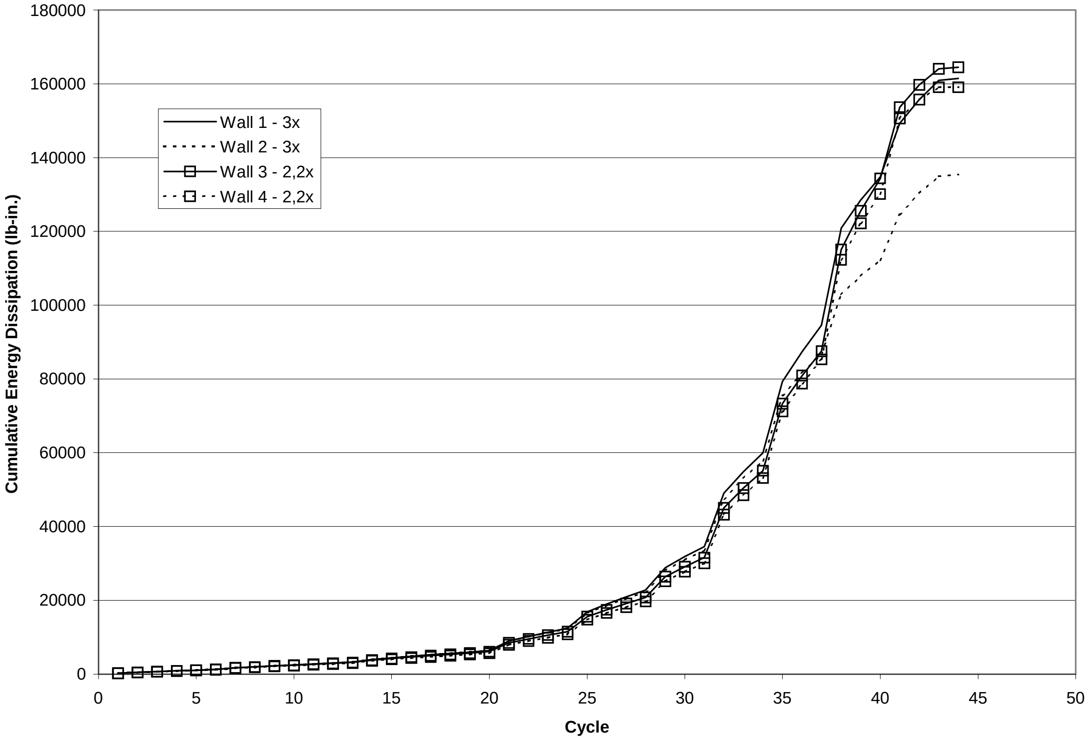
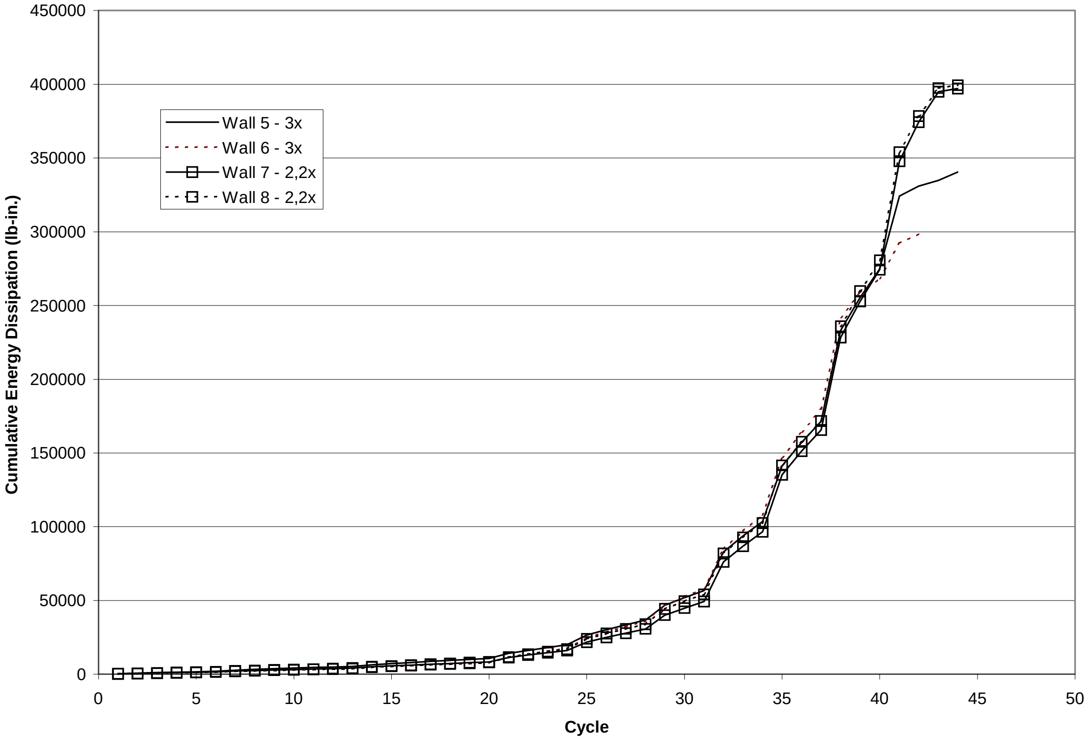


Figure 6. Energy dissipation curves for walls 5-8 (870 plf walls)



Appendix A

Figure A1. Load-displacement hysteresis loops for Wall 1

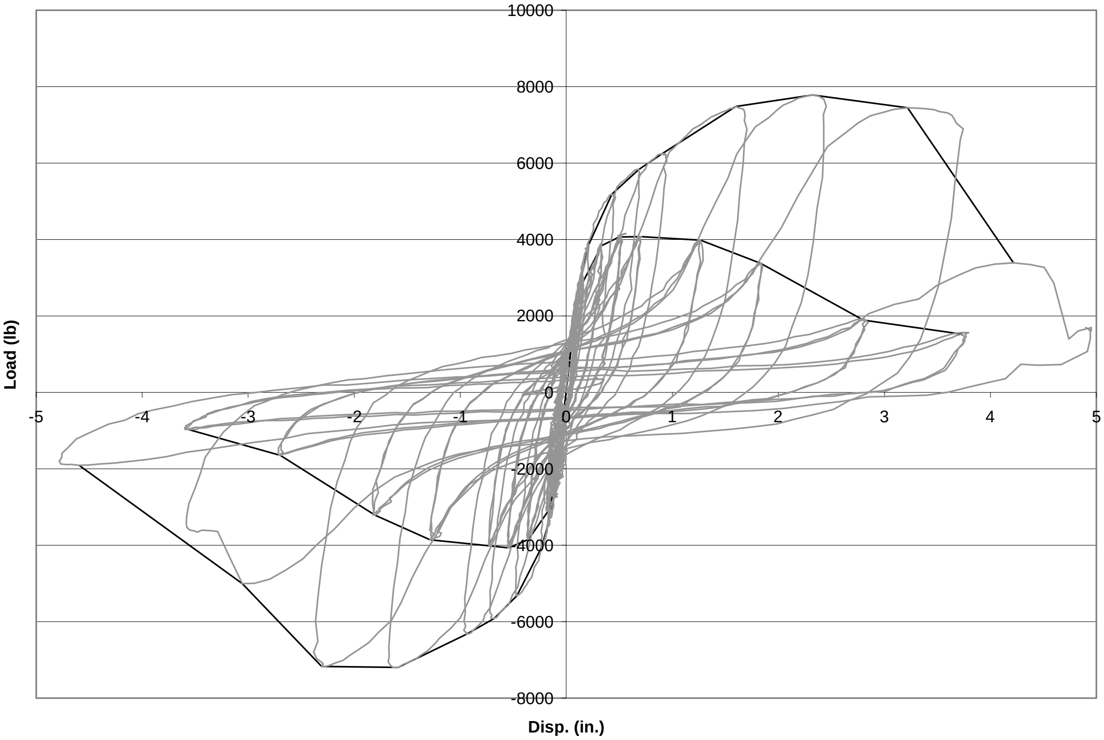


Figure A2. Load-displacement hysteresis loops for Wall 2

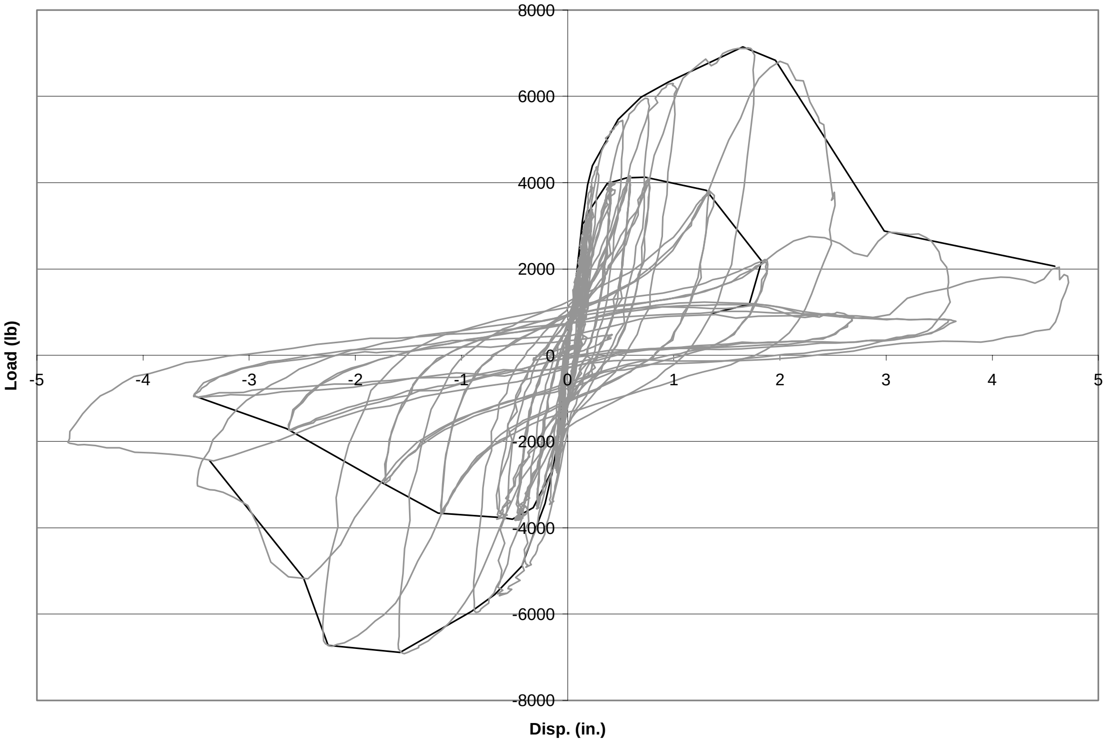


Figure A3. Load-displacement hysteresis loops for Wall 3

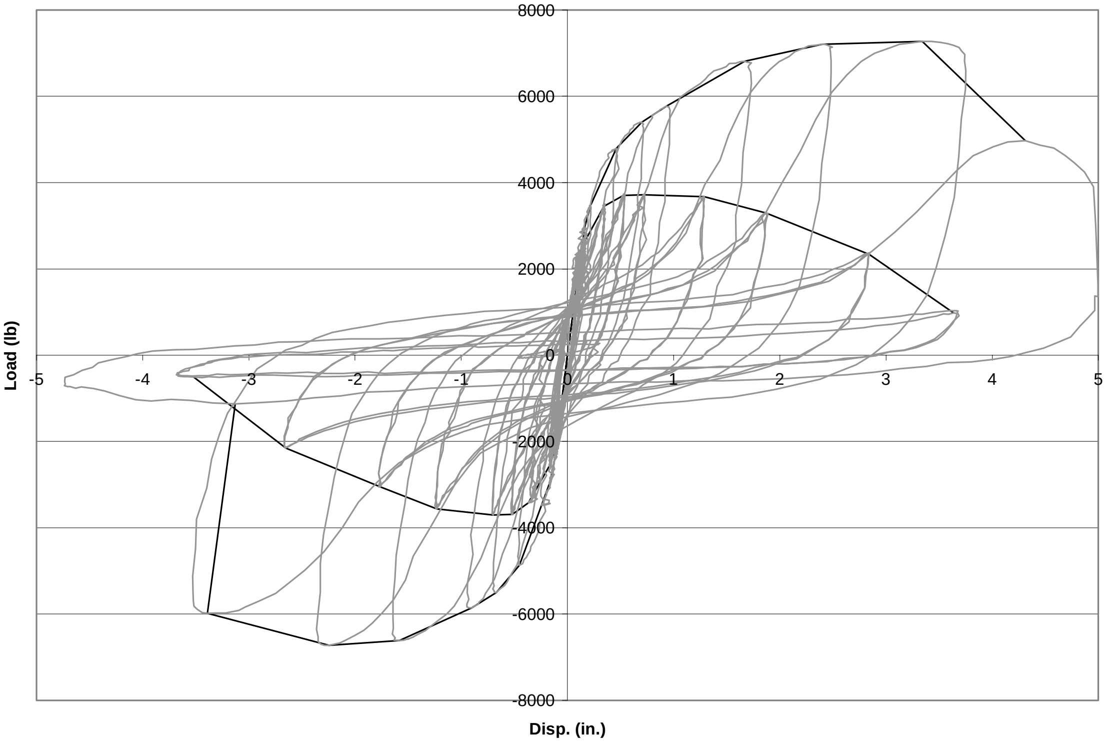


Figure A4. Load-displacement hysteresis loops for Wall 4

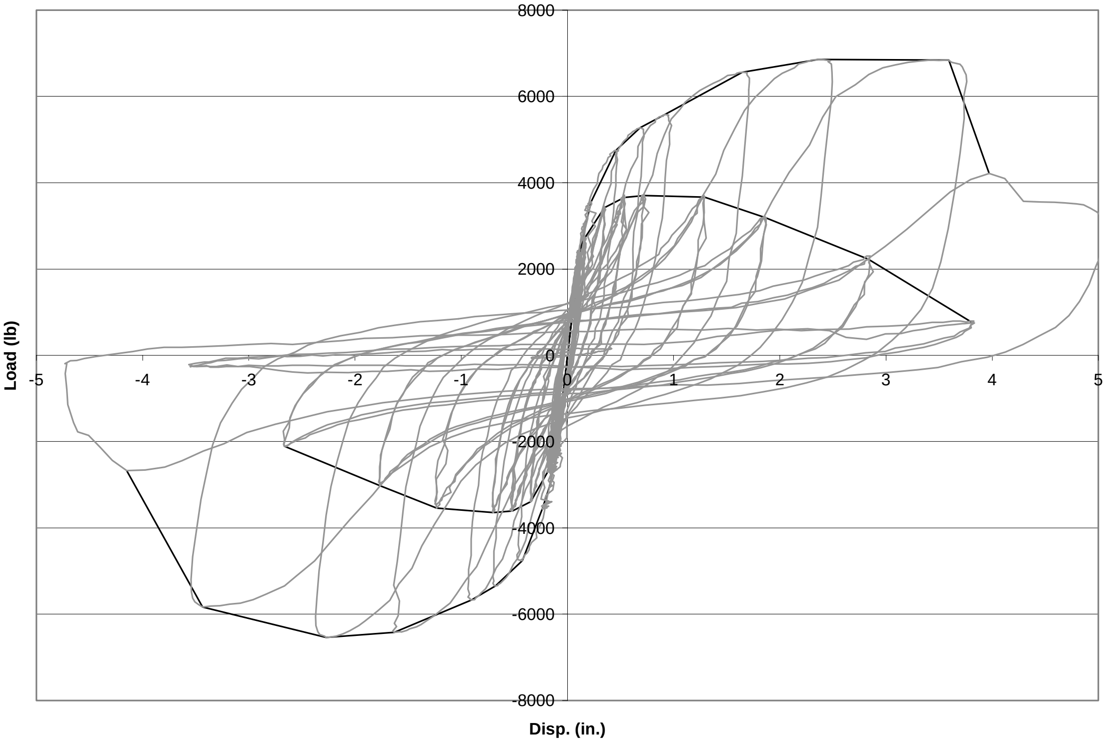


Figure A5. Load-displacement hysteresis loops for Wall 5

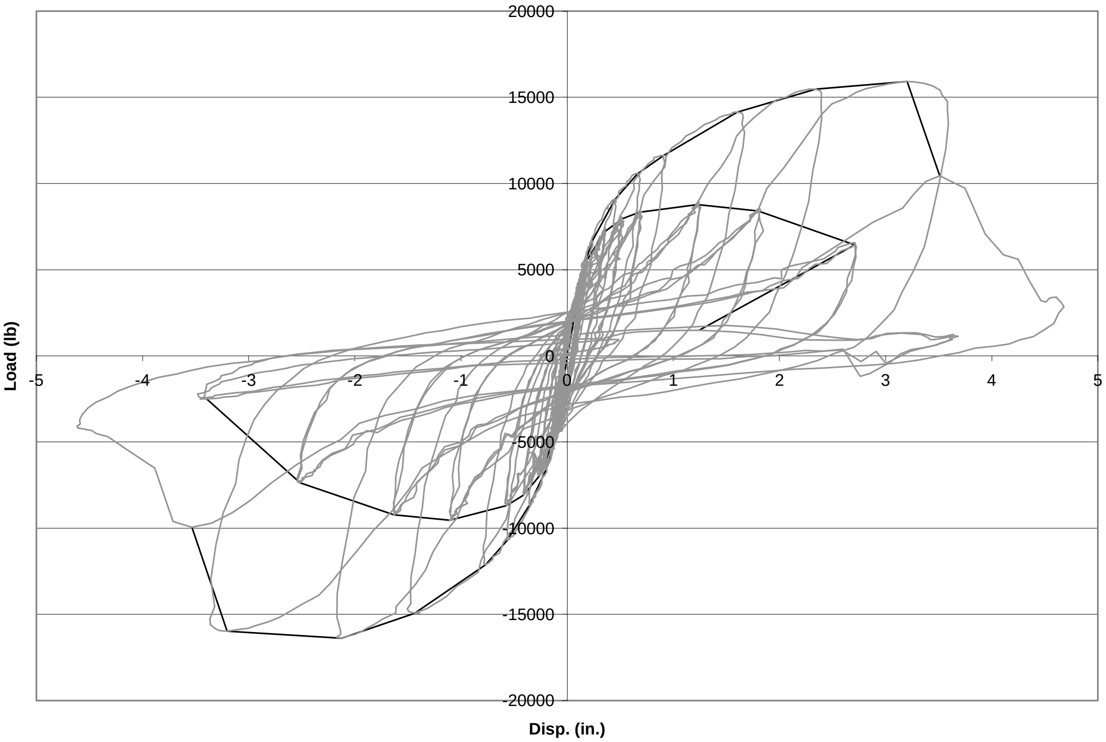


Figure A6. Load-displacement hysteresis loops for Wall 6

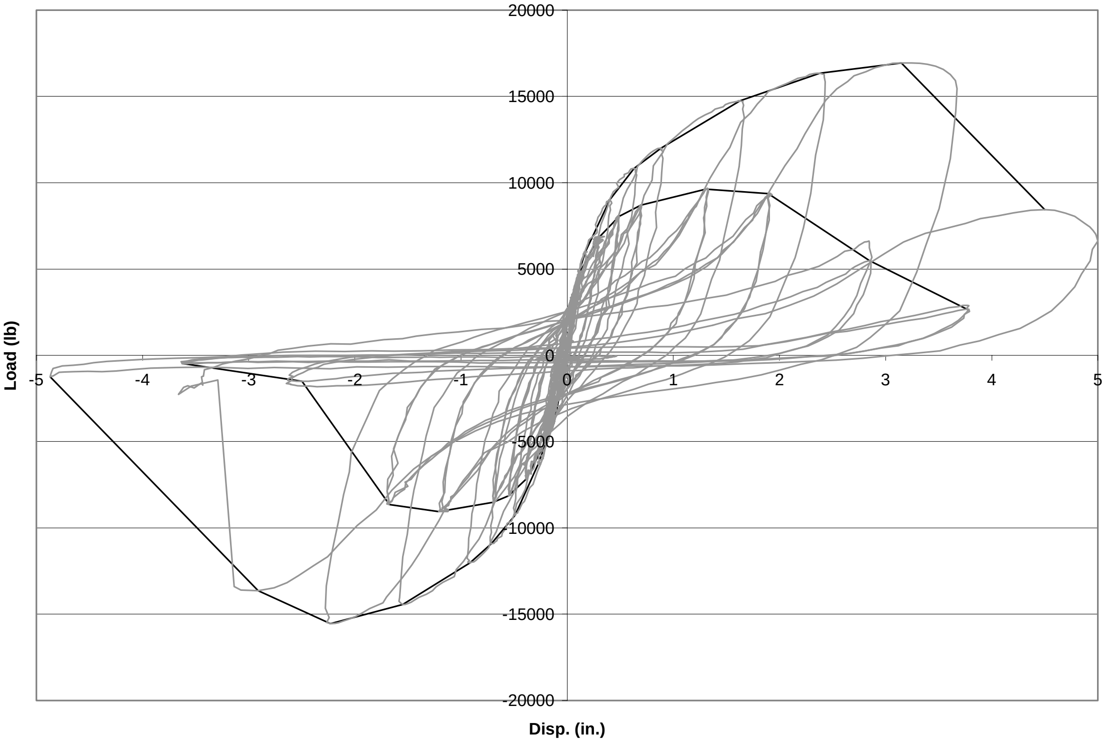


Figure A7. Load-displacement hysteresis loops for Wall 7

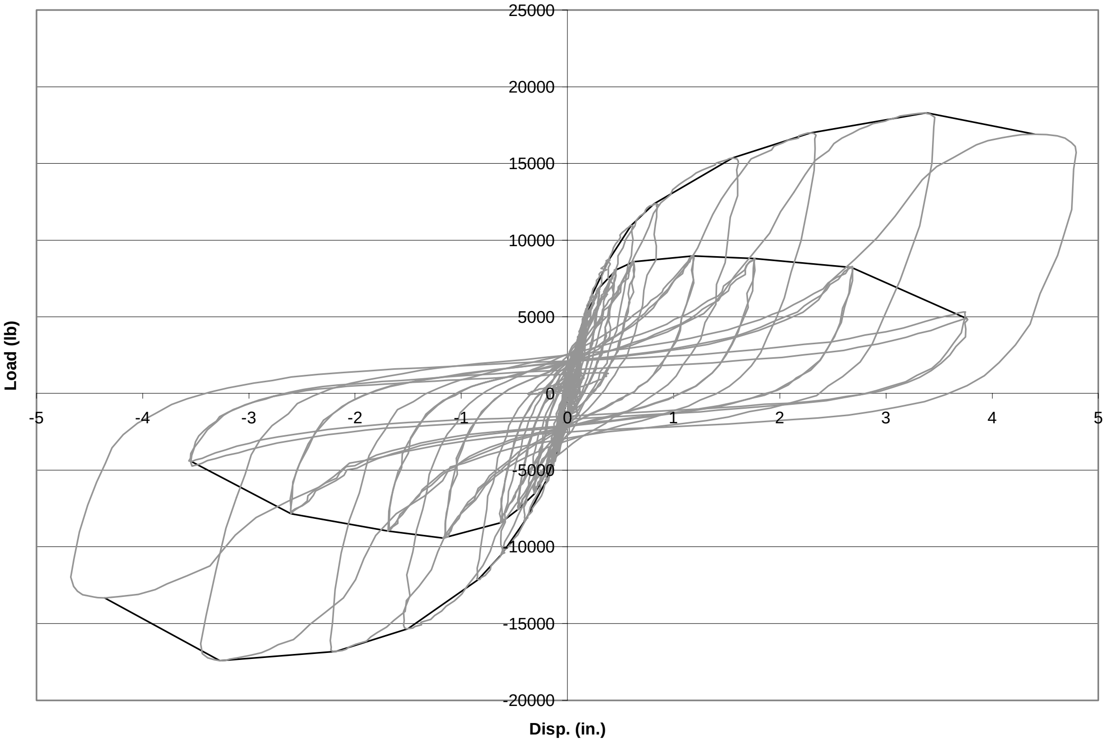
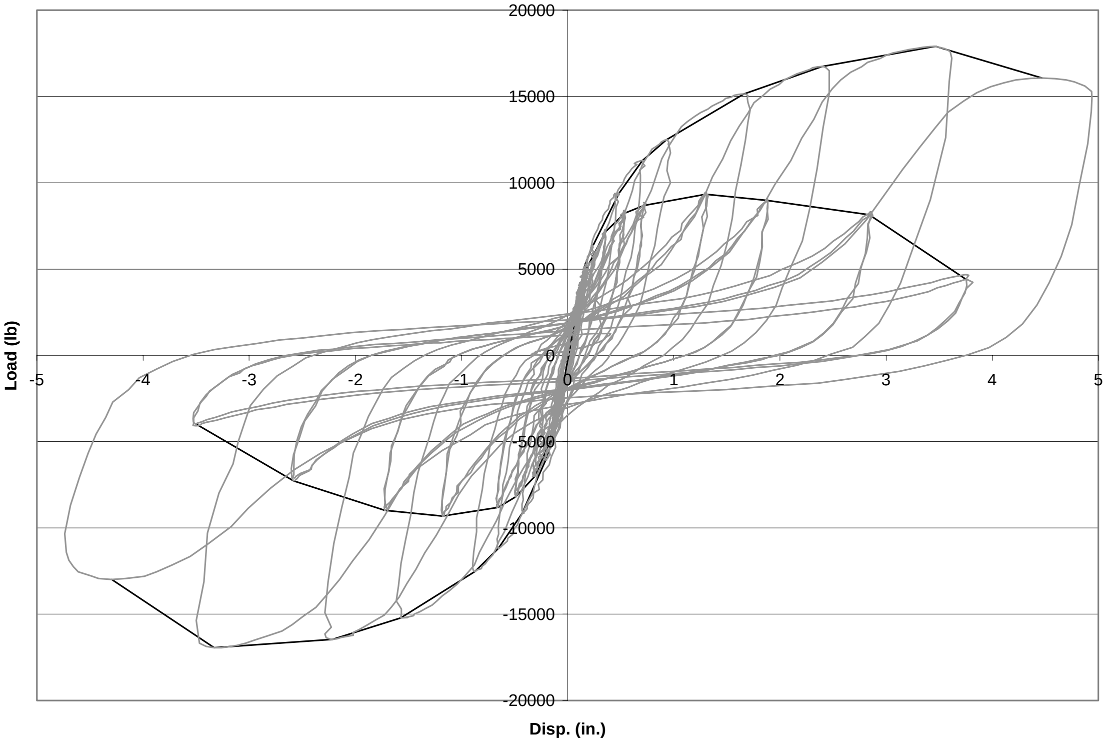


Figure A8. Load displacement hysteresis loops for Wall 8



Appendix B

	
Figure B1. Typical controlling failure mode. Slots shown in lumber end post from nails working (note: slots oriented toward panel centroid). Wall 7.	Figure B2. Stitch nailed double 2x in Wall 8. Photo was taken after testing was complete. Note: OSB panel separation from framing at sill plate, also parallel line marks on double 2x for visual observation during testing.
	
Figure B3. Typical nail yield and subsequent withdrawal from sill plate. Wall 5.	Figure B4. Nail withdrawn after testing. Typical nail yielding controlling shear wall failure. Wall 5.
	
Figure B5. Edge tear, nail head pull through and nail yield. Wall 5.	Figure B6. Edge tear, nail head pull through and nail yield. Wall 8.

	
Figure B7. End post failure of Wall 2.	Figure B8. End post failure of Wall 2.
	
Figure B9. End post failure of Wall 6.	Figure B10. End post failure of Wall 6.