

Cyclic tests of engineered shear walls with different bottom plate and anchor bolt washer sizes (Phase II)

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Summary Table. Phase II plate washer study.

Wall designation	Bottom plate	Washer type	P _{peak} (lbf)	Δ _{peak} (in.)	Energy ¹ (in-lb)
E1	2x6	Round washer (1.75 in. dia. x 1/8 in.)	11044	3.31	149772
E2			11301	2.2	95007
E3			11081	2.28	98638
Avg. E ²			11142	2.6	96823
F1	2x6	Square plate washer (3 in. x 3/8 in.)	10943	2.22	95658
F2			11149	2.28	97524
F3			11506	2.27	97407
Avg. F			11199	2.26	96863
G1	2x6	Round washer (1.75 in. dia. x 1/8 in.)	18408	1.67	116609
G2			19841	1.63	149444
G3			18535	2.18	144121
Avg. G			18928	1.83	136725
H1	2x4	Round washer (1.75 in. dia. x 1/8 in.)	14054	2.04	98990
H2 ³			-	-	-
H3			14145	3.00	120250
Avg. H			14100	2.52	109620

¹Area under hysteresis loops up to the first complete loop beyond P_{peak}.

²Excludes E1 from average Energy because P_{peak} occurs one loop beyond walls E2 and E3.

³Construction defect - incorrectly installed sheathing.

Note: anchor bolt nuts tightened to approximately 40 ft-lbs torque.

Summary Conclusions

This study examined the effect of washer size, used at bottom plate anchor bolts, on the performance of engineered wood shear walls. Complete framing details, load deformation behavior and observations from testing are shown on the following pages. The test setup was in accordance with methods in ASTM E2126 Standard Test Methods for Cyclic (Reversed) Load Test for Shear Resistance of Framed Walls for Buildings. Walls E and F which were identical except for washer size showed similar performance based on peak capacity, deflection at peak capacity, Δ_{peak}, and observations of failures at the conclusion of testing.

Scope of Study

A series of cyclic shear wall tests to determine the influence of bottom plate and plate washer size on the performance of engineered wood frame shear walls was conducted. This testing, called “Phase II”, used the same test methods as used in the Phase I study (completed in May 2004 by David Rosowsky, Lori Elkins and Cameron Carroll).

Testing

All shear wall testing was conducted at Oregon State University in the Wood Science and Engineering Department’s Gene D. Knudson Wood Engineering Laboratory. The test assembly used for cyclic tests is shown in Figure 1.

The test specimens were bolted to a steel beam which was solidly attached to the strong floor of the testing facility to simulate a fixed foundation. The test walls were loaded using a servo controlled hydraulic actuator that can apply a maximum load of 490 kN (110 kips) with a total stroke of 254 mm (10 in). The hydraulic actuator is controlled by an MTS 406 servo controller. The hydraulic actuator was attached to the strong wall and supported by a 102 mm (4 in) hydraulic cylinder that could be either raised or lowered during testing to eliminate any vertical load being applied to the test specimen. The raising and lowering of the hydraulic cylinder was facilitated by oil over air accumulator with a pressure of approximately 690 kPa (100 psi).

During testing the shear walls were instrumented with a number of load and displacement recording devices which are illustrated in Figure 1. To measure the load and displacement at the top of the wall, the hydraulic actuator is equipped with a load cell and an internal linearly variable differential transformer (LVDT). Additional LVDT’s were placed at the base of each end of the wall to measure uplift.

All walls were tested under cyclic load. CUREE protocol for ordinary ground motion with a reference displacement (Δ_{ref}) of 3.3 inches was used to test all walls.

Test Specimens

A description of walls tested is shown in Figures 2 to 4.

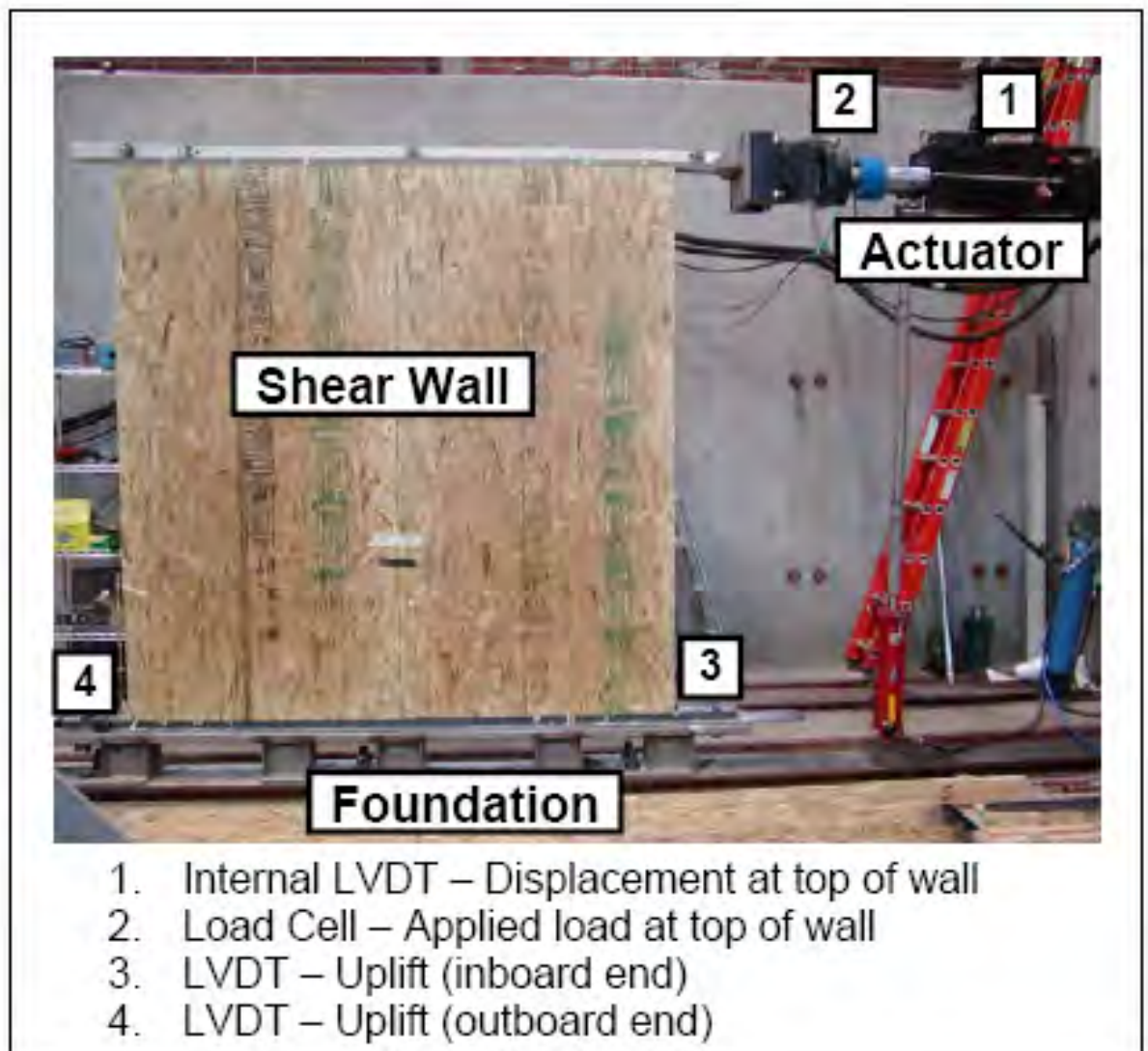


Figure 1. Cyclic testing frame

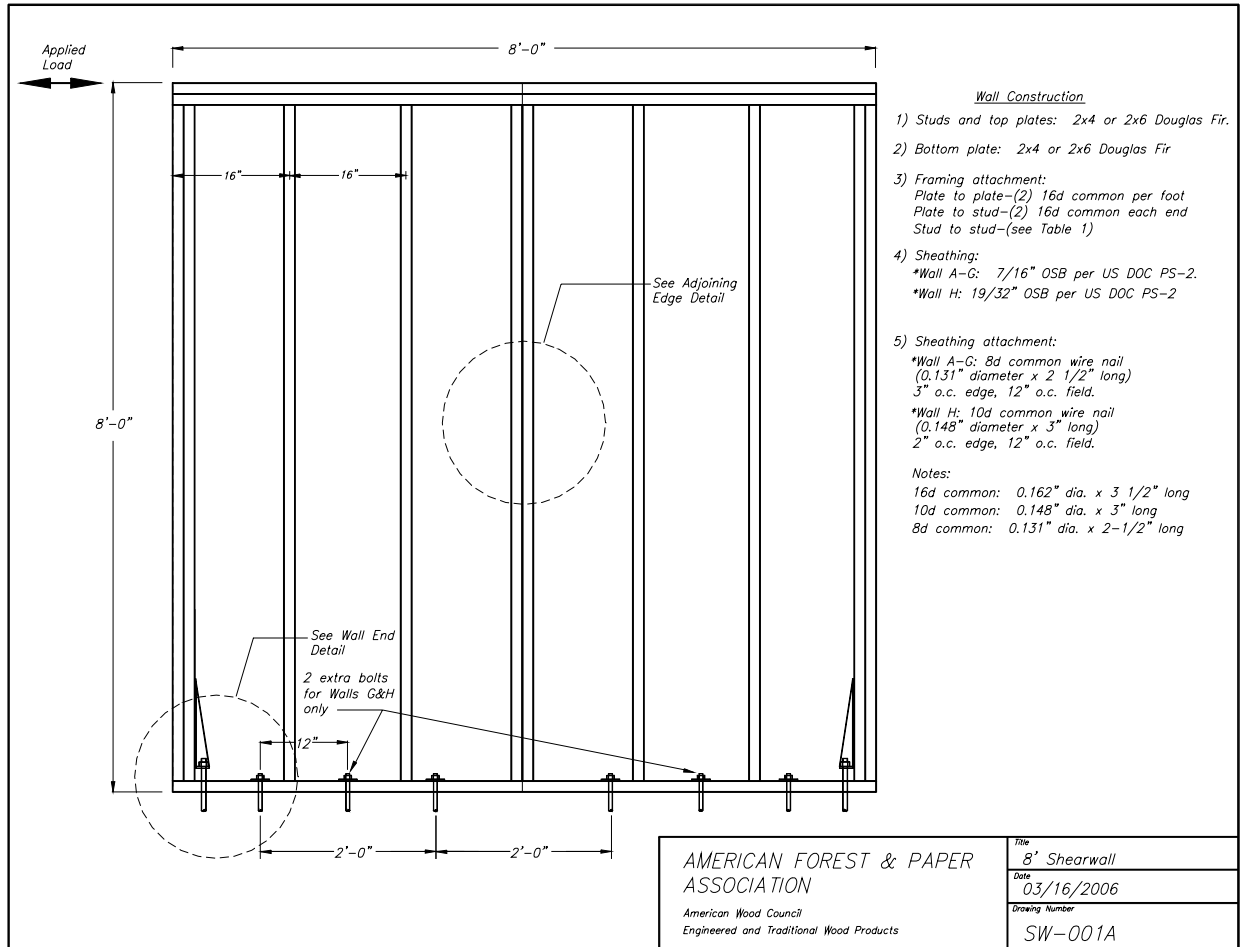


Figure 2. Wall Construction Details

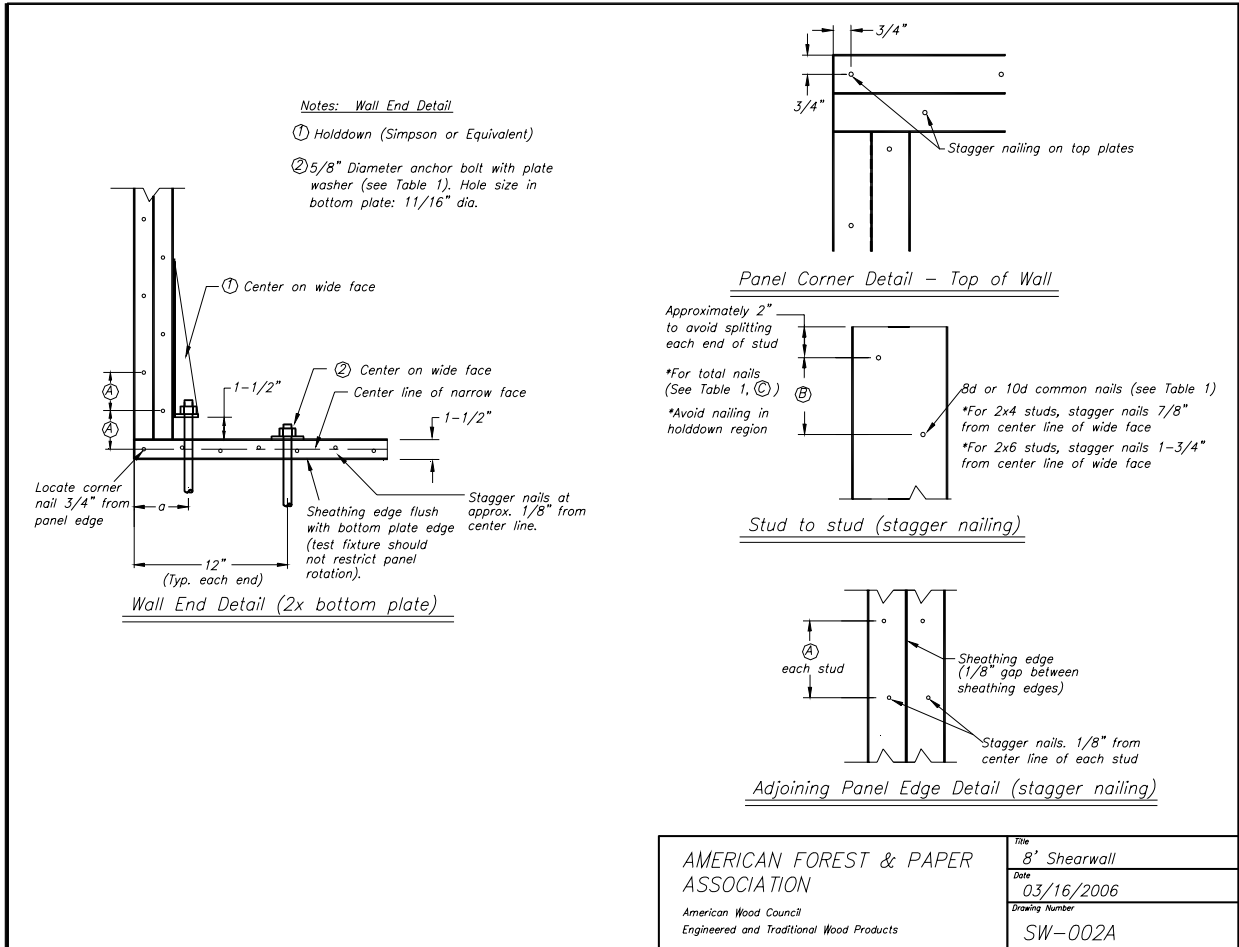


Figure 3. Wall Details

Table 1.

Phase	Specimen	Bottom Plate	Plate Washer	Replicates	Sheathed Sides	(A) Nail Spacing	(B) Nail Spacing	(C) No. of Nails	Holddown	
1	Wall A	2x4	2-1/2" square x 1/4"	(3)	One	3 inch	4-1/4 inch	(21) 10d Common	PHD 5	
	Wall B	2x4	3" square x 3/8"	(3)	One	3 inch	4-1/4 inch	(21) 10d Common	PHD 5	
	Wall C	2x4	Plain Washer (1 3/4" dia. x 0.125" thick)	(3)	One	3 inch	4-1/4 inch	(21) 10d Common	PHD 5	
	Wall D	2x4	2" square x 3/16"	(3)	One	3 inch	4-1/4 inch	(21) 10d Common	PHD 5	
2	Wall E	2x6	Plain Washer (1 3/4" dia. x 0.125" thick)	(3)	One	3 inch	3-1/2 inch	(21) 10d Common	PHD 5	
	Wall F	2x6	3" square x 3/8"	(3)	One	3 inch	3-1/2 inch	(21) 10d Common	PHD 5	
	Special Construction Details. Approximate wall capacity = 20,000 lbf									
	Wall G	2x6	Plain Washer (1 3/4" dia. x 0.125" thick)	(3)	Two	3 inch	1-3/4 inch	(42) 10d Common	HDQ 8	
Wall H	2x4	Plain Washer (1 3/4" dia. x 0.125" thick)	(3)	One	2 inch	-	-	HDQ 8		

*Load Protocol: CUREE Standard Protocol - 1 cycle per 4 seconds

*Bottom plates: Treated-incised

*For Wall G and H, expected wall capacity will be approximately 20,000 lbf versus approximately 10,000 lbf for Walls A-F.

Changes to wall details for Wall H are:

- 6 anchor bolts versus 4 for walls A-F
- Wall H to have 4x6 end post and 3x4 post at adjoining panel edge

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	Date 03/20/2006
	Drawing Number SW-003A

Figure 4. Test Matrix

Table 1. Testing observations

Wall designation	Washer type	Notes/observations:	Dominant failure mode
E1	Round Washer	Separation of sheathing from end studs and some interior studs. Some splitting of bottom plate along narrow face at the ends of the wall.	Fastener failure
E2		Separation of studs from top plate at corners of wall. Separation of sheathing material from studs predominately around the perimeter. Some splitting of bottom plate occurred starting at hold-downs at both ends.	Fastener failure
E3		Separation of double top plate from double end stud at top right corner of wall. Interior and center studs lifted up from bottom plate during testing. Splitting of bottom plate along its length. Sheathing material completely separated from double end studs at right end of the wall.	Fastener failure
F1	3" square plate washer	Separation of studs from double top plate at ends. Interior and center studs lifted up from bottom plate. Sheathing pulled away from end studs and bottom plate. Splitting of bottom plate that started along narrow face and extended to approximately the edge of the plate washer on the wide face.	Bottom plate failure
F2		Separation of studs from double top plate at ends. Interior and center studs lifted up from bottom plate. Bottom plate splitting along the edge of the plate washer. Pull through of nails through sheathing mostly on perimeter of wall.	Fastener failure
F3		Double top plate separated from end studs at right end of wall. Splitting of bottom plate on narrow face from OSB pulling up. Some additional splitting on wide face of bottom plate to the edge of the square plate washers. Interior studs lifted up from bottom plate but attached to sheathing.	Fastener failure

Table 2. Testing Observations

Wall designation	Washer type	Notes/observations:	Dominant failure mode
G1	Round washer	Nails pulled completely out of OSB along bottom edge of the wall. Yielding of nails connecting two center studs together. Splitting along the narrow face of double end stud at south end of wall. Splitting in bottom plate mainly due to tension across the grain on the narrow face.	Bottom plate failure (splitting)
G2		Nail withdrawal along bottom edge of the wall. Separation of inter-nailed center studs. Splitting along the narrow face of center stud.	Bottom plate failure (splitting)
G3		Nail withdrawal along bottom edge of the wall. Splitting in bottom plate due to both tension across the grain on narrow face and cross grain bending on wide face of bottom face.	Bottom plate failure (splitting)

Table 3. Testing Observations

Wall designation	Washer type	Notes/observations:	Dominant failure mode
H1	Round washer	Double top plate split along narrow face and completely separated from wall. Also observed splitting along center stud of the wall. Some minor splitting in the bottom plate was also observed.	Splitting of center stud and top plate
H2		Data not available due to construction defect	
H3		Studs lifted up from the bottom plate at the ends. The threads of the holddown anchor bolt at the north end of the wall failed resulting in significant uplift and the corner and subsequent splitting of the bottom plate plate.	<ul style="list-style-type: none"> - Failure of threads on holddown anchor bolt - Bottom plate failure (splitting)

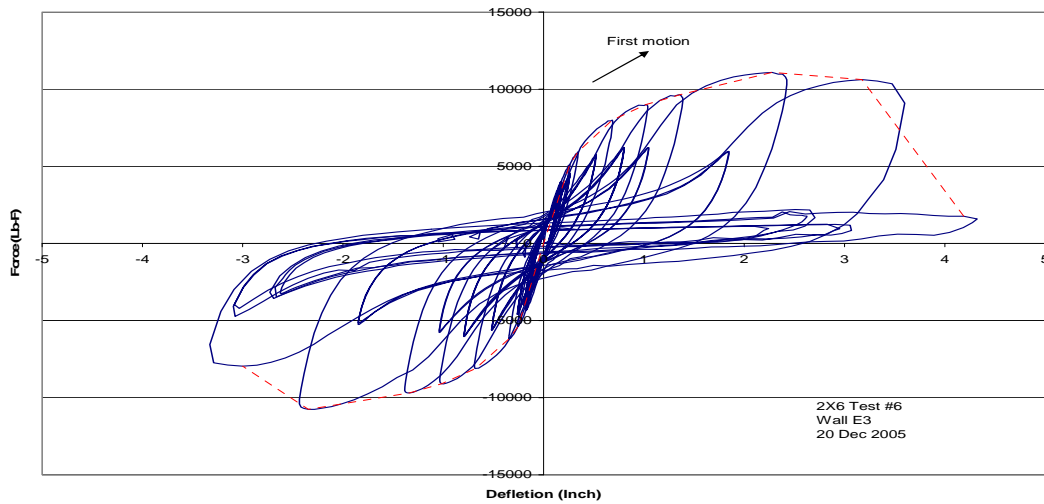
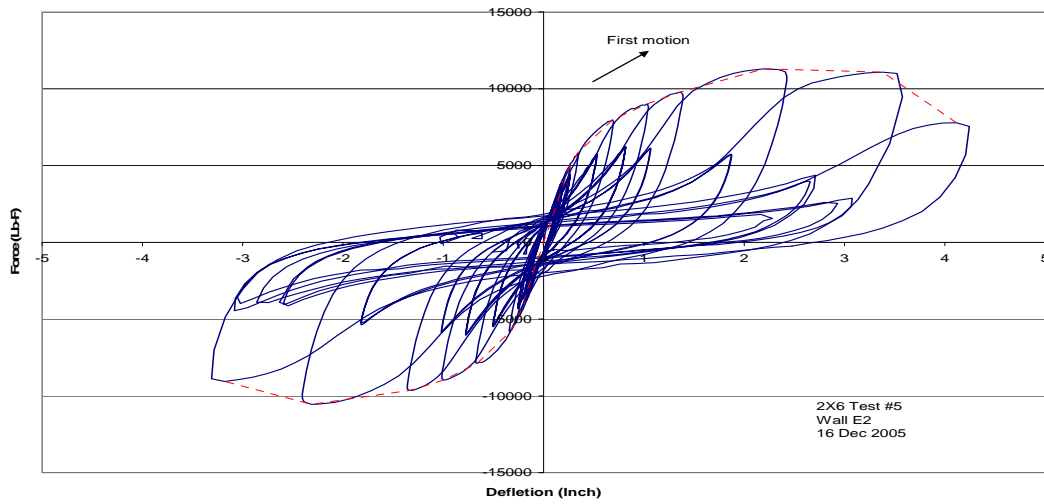
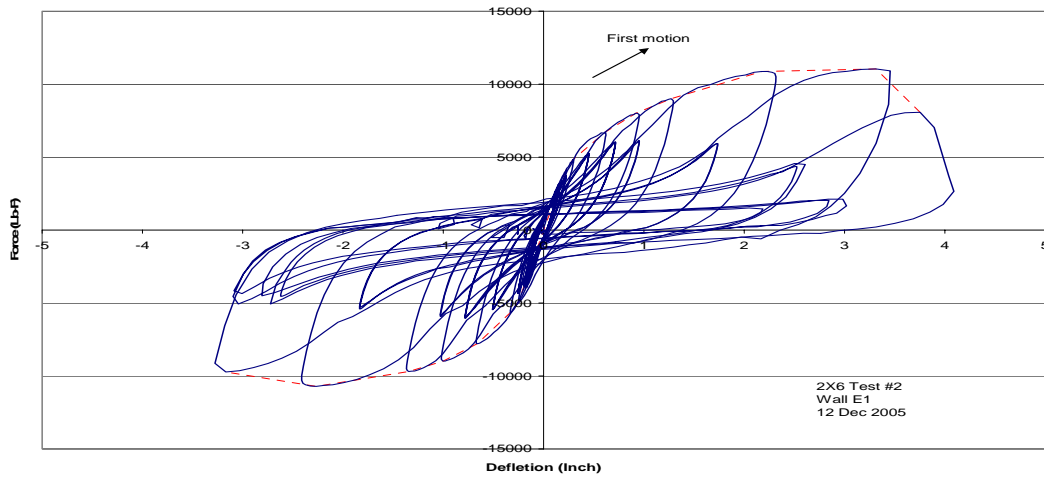


Figure 5. Hysteresis and backbone curves for Walls E1-E3 (Round washers)

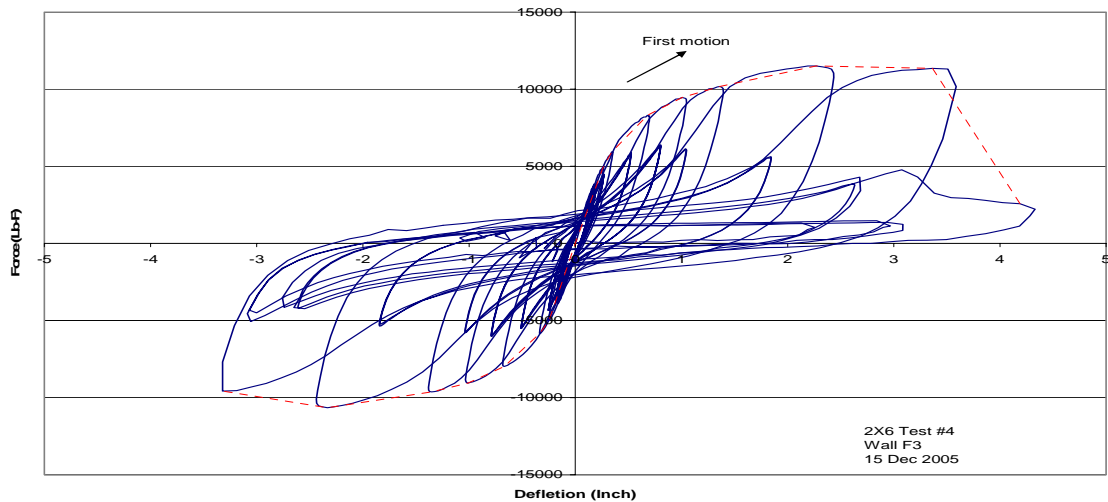
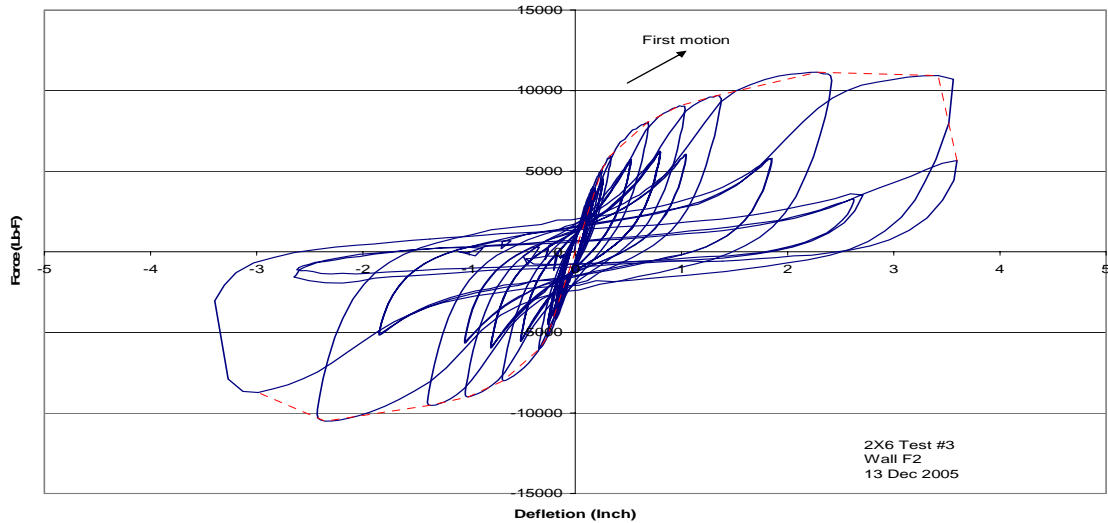
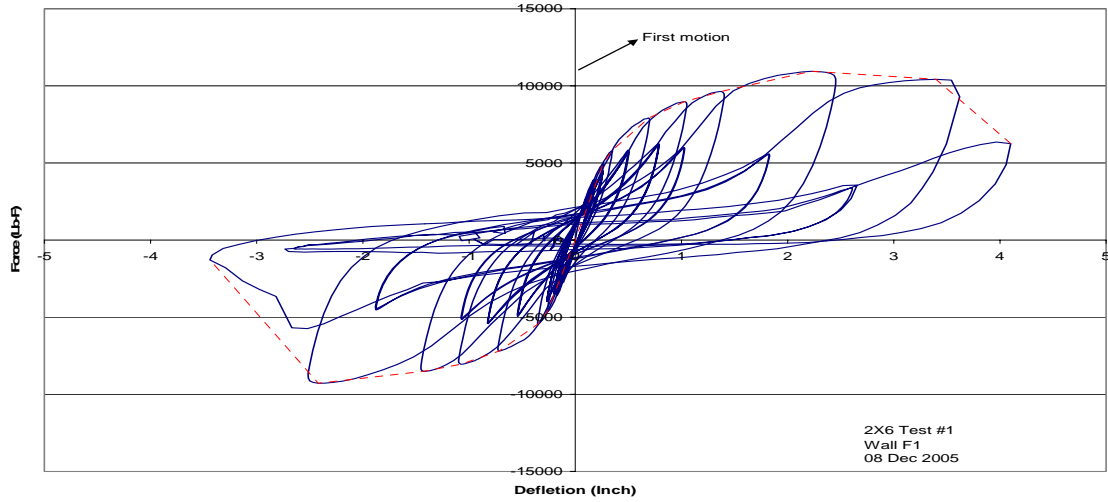


Figure 6. Hysteresis and backbone curves for Walls F1-F3 (square plate washers)

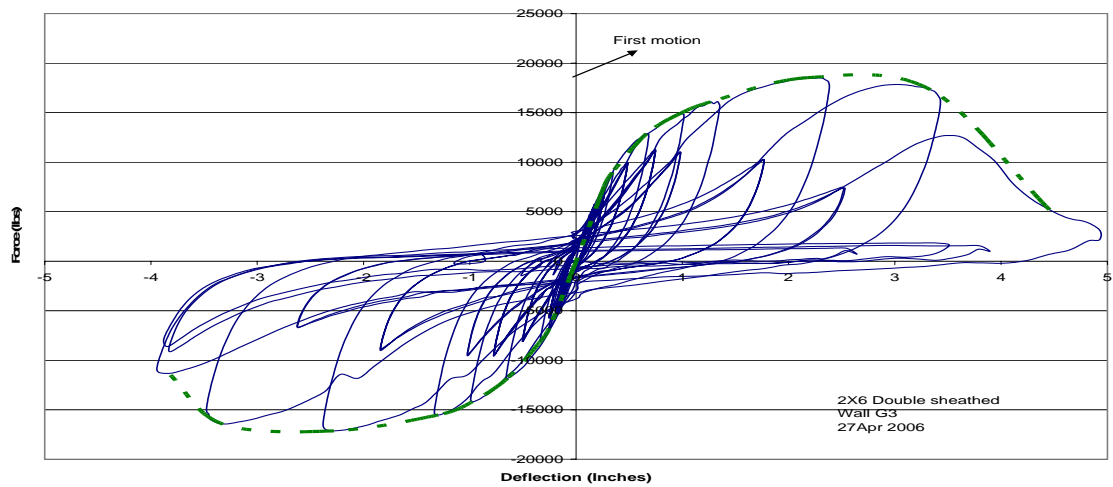
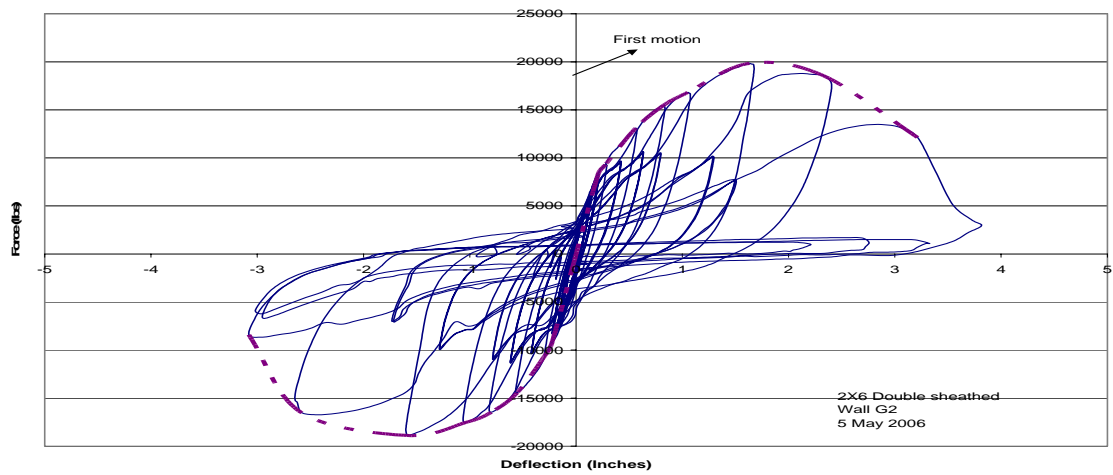
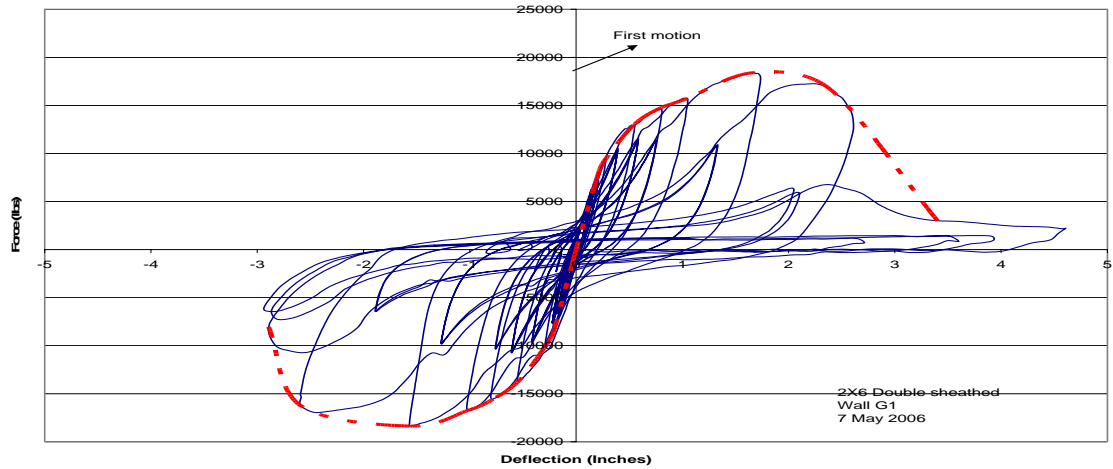


Figure 7. Hysteresis and backbone curves for Walls G1-G3 (Round washers)

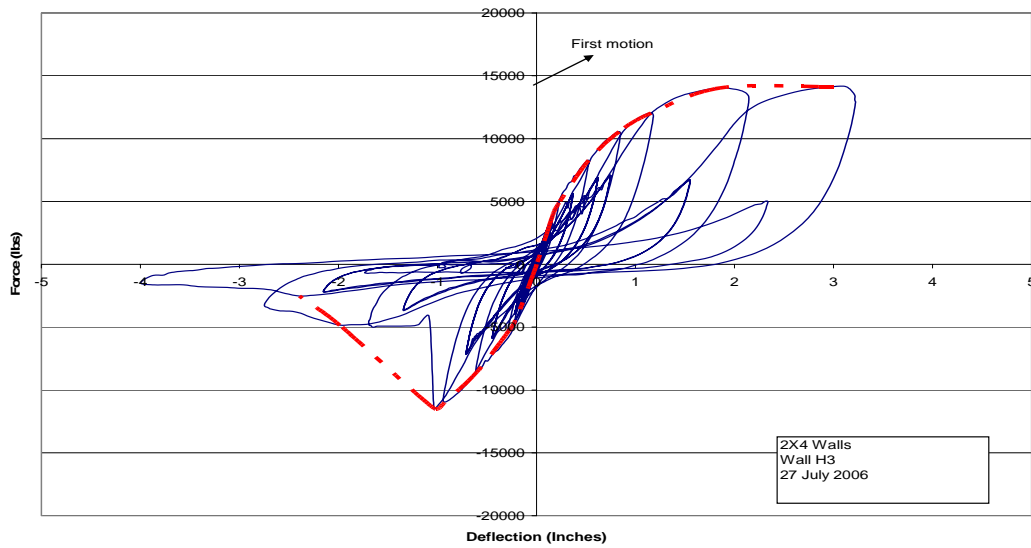
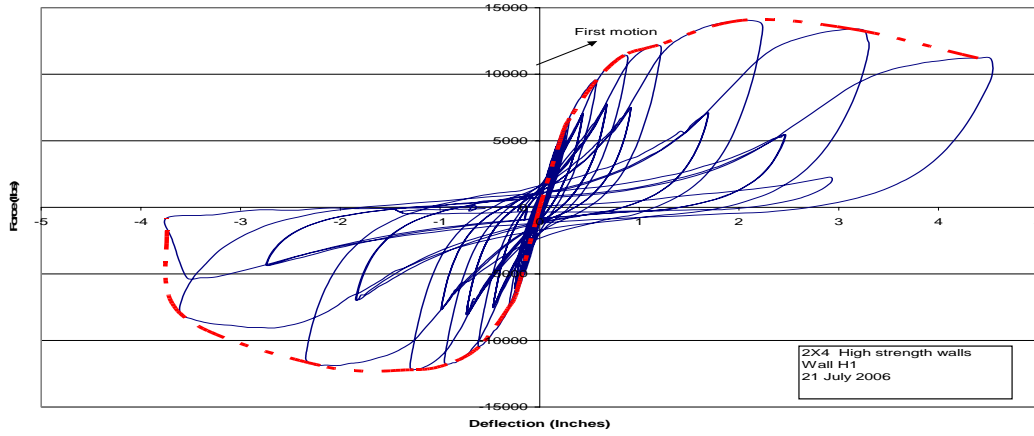


Figure 8. Hysteresis and backbone curves for Walls H1 and H3 (Round Washers)



Figure 9. Splitting of bottom plate and separation of sheathing (Wall E2)



Figure 10. Splitting of bottom plate and separation of sheathing (Wall E2)



Figure 11. Separation of sheathing and splitting of bottom plate (Wall F1)



Figure 12. Splitting of bottom plate to the outside of square plate washer (Wall F1)



Figure 13. Splitting along narrow face on west side of wall (Wall G2)



Figure 14. Splitting along narrow face on west side of wall (Wall G2)

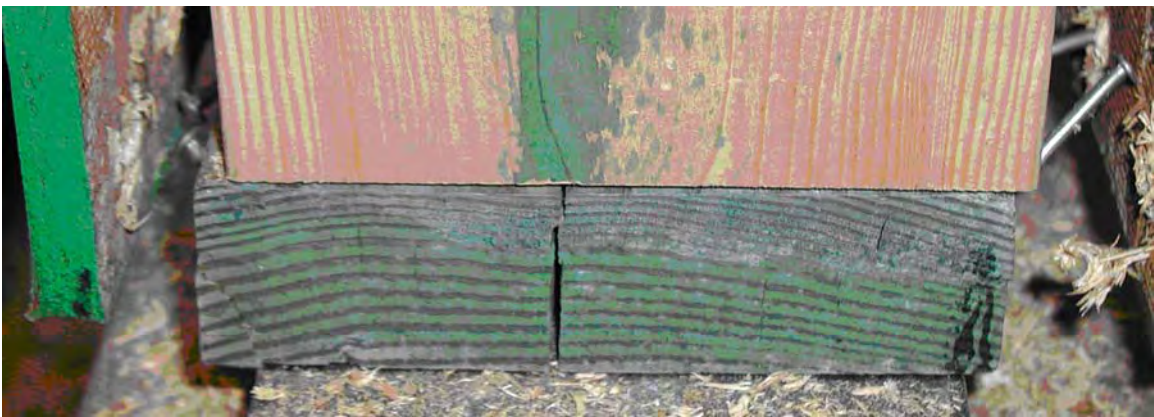


Figure 15. Splitting of bottom plate at south end of wall (Wall G2)



Figure 16. Splitting of bottom plate (Wall H1)



Figure 17. Splitting on narrow face of bottom plate (Wall H1)



Figure 18. Slight yielding of nails around the perimeter (Wall H1)



Figure 19. Wall H1 after testing.



Figure 20. Splitting of center stud (Wall H1)