Cyclic tests[1] of engineered shearwalls considering different plate washer sizes

Prepared for: American Forest & Paper Association (AF&PA)

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Summary Table

Wall designation	P_{max} (lbs)	Δ @ P_{max} (in.)	load @ $0.8P_{max}$ (lbs)	Energy[(1)] (in.-lbs)
A1	10428	3.44	9500	84370
A2	11334	3.07	10487	76433
A3	11815	2.96	10895	78042
Avg. A	***11192***	***3.16***	***10294***	***79615***
Avg. A *(excl. A1)*	***11575***	***3.02***	***10691***	***77238***
B1	11156	2.81	10084	79779
B2	12053	2.98	11229	90002
B3	11682	2.84	10652	80577
Avg. B	***11630***	***2.88***	***10655***	***83453***
C1	11774	2.58	10062	58339
C2	11421	2.69	10593	64979
C3	11943	2.83	11219	67161
Avg. C	***11713***	***2.70***	***10625***	***63493***
D1	11600	2.81	10863	77540
D2	11407	2.81	10611	76369
D3	10148	2.85	9150	71434
Avg. D	***11052***	***2.82***	***10208***	***75114***

A: 2.5 in. square × 1/4 in. plate washer
B: 3 in. square × 3/8 in. plate washer
C: standard round washer (1.75 in. diam. × 1/8 in.)
D: 2 in. square × 3/16 in. plate washer (tested March 2004)
Note: washers tightened to approximately 40 ft-lbs torque

(1) Area under hysteresis loops up to the first complete loop beyond P_{max}

Summary Conclusion

This study examined the effect of washer size (used at the anchorage) on the performance of engineered wood shearwalls built with a treated sole plate (bottom plate). Complete framing details of the wall specimens are shown on the following pages. No statistically significant differences in performance, as measured by peak capacity and deflection capacity, were observed[2].

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[1] 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*. The cyclic loading protocol is shown in Appendix A.

[2] Analysis of variance (ANOVA) was performed. The mean peak capacities were found to have no statistical differences at the 5% significance level. The means of the corresponding deflections (at P_{max}) were found to have no statistical differences at the 2% significance level.

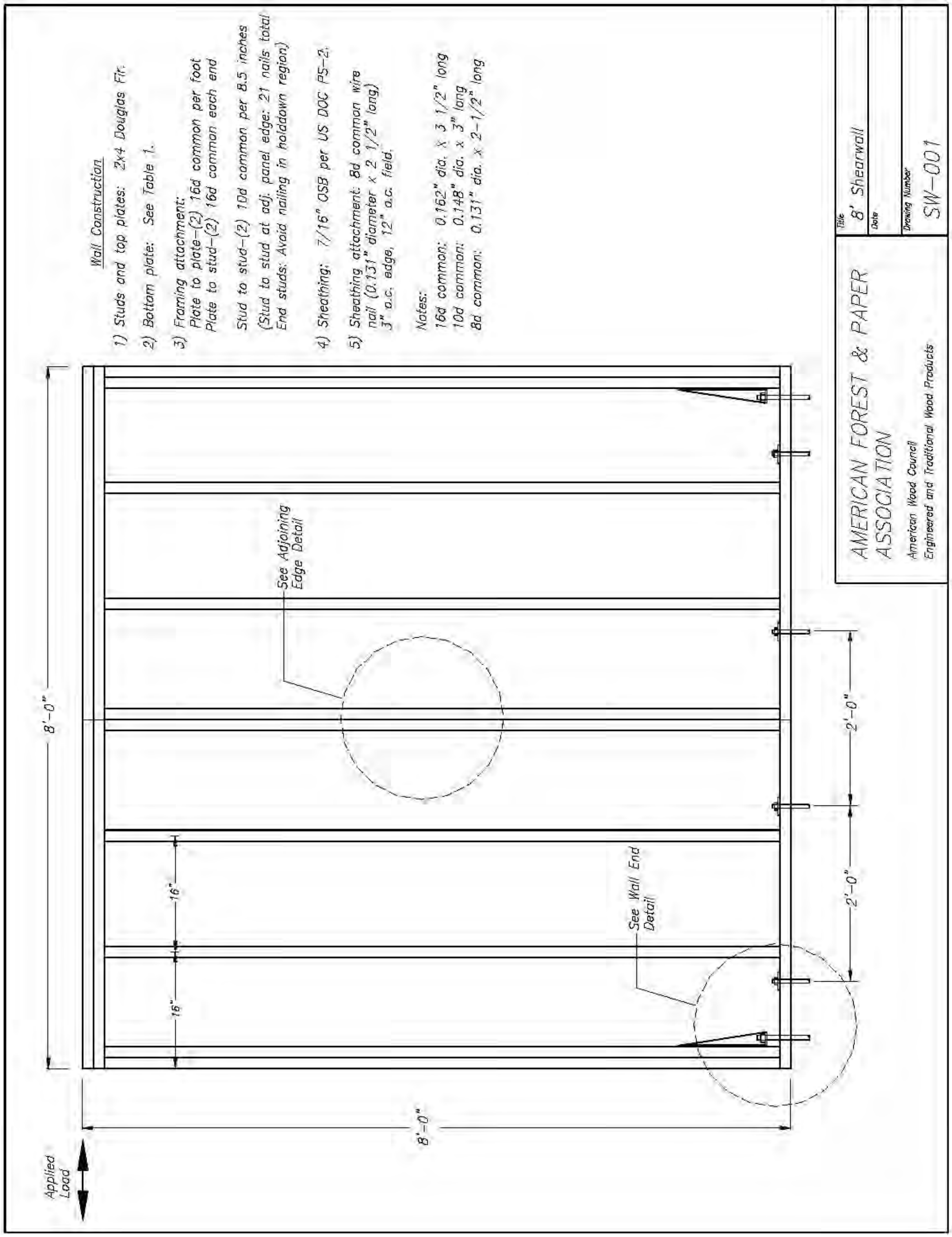
Summary Notes/Observations:

Wall designation	Washer type	Notes/observations:	Dominant failure mode
A1	2.5 in. square plate washer	Sheathing separated from studs at center of wall.	Fastener failure
A2		Interior studs separated from sole plate. Sheathing separated from studs at center of the wall.	Fastener failure
A3		Same as A2 (with some splitting of sole plate).	Fastener failure
B1	3 in. square plate washer	Sole plate split at hold-downs. One hold-down completely ripped from end studs (bent screws). Separation at middle double stud. Fewer failures of edge sheathing fasteners.	Fastener failure
B2		Sheathing separated from studs at outside and bottom edges of wall, however middle seam intact. End studs started to split at hold-down. Sole plate had little damage.	Fastener failure
B3		Fastener failure at sheathing edges at ends of wall. Bottom edge of sheathing pulled away from sole plate along interior studs. (Some superficial splitting of sole plates.) Bottom of end studs (near sole plate) split.	Fastener failure
C1	standard round washer	Sole plate failed (split) along ¾ of length. Bottom of sheathing pulled away from sole plate. Little damage on other edges. End stud split along hold-down screws. Interior studs separated from sole plate.	Sole plate failure (splitting)
C2		Sole plate failed along ½ of length. One of the middle studs split from bottom plate (up about 12”) and from top plate (down about 30”). One sheathing panel pulled away from studs along edge and bottom of wall, with less damage along middle seam. The other panel had complete failure along middle seam, some failure along bottom, and little failure at end.	Sole plate failure (splitting)
C3		Sole plate failed. Similar to C2. Middle double stud split at end near sole plate. One end stud split along (one line of) hold-down screws. Sheathing pulled away from bottom half of end studs, and along sole plate. Middle seam intact.	Sole plate failure (splitting)

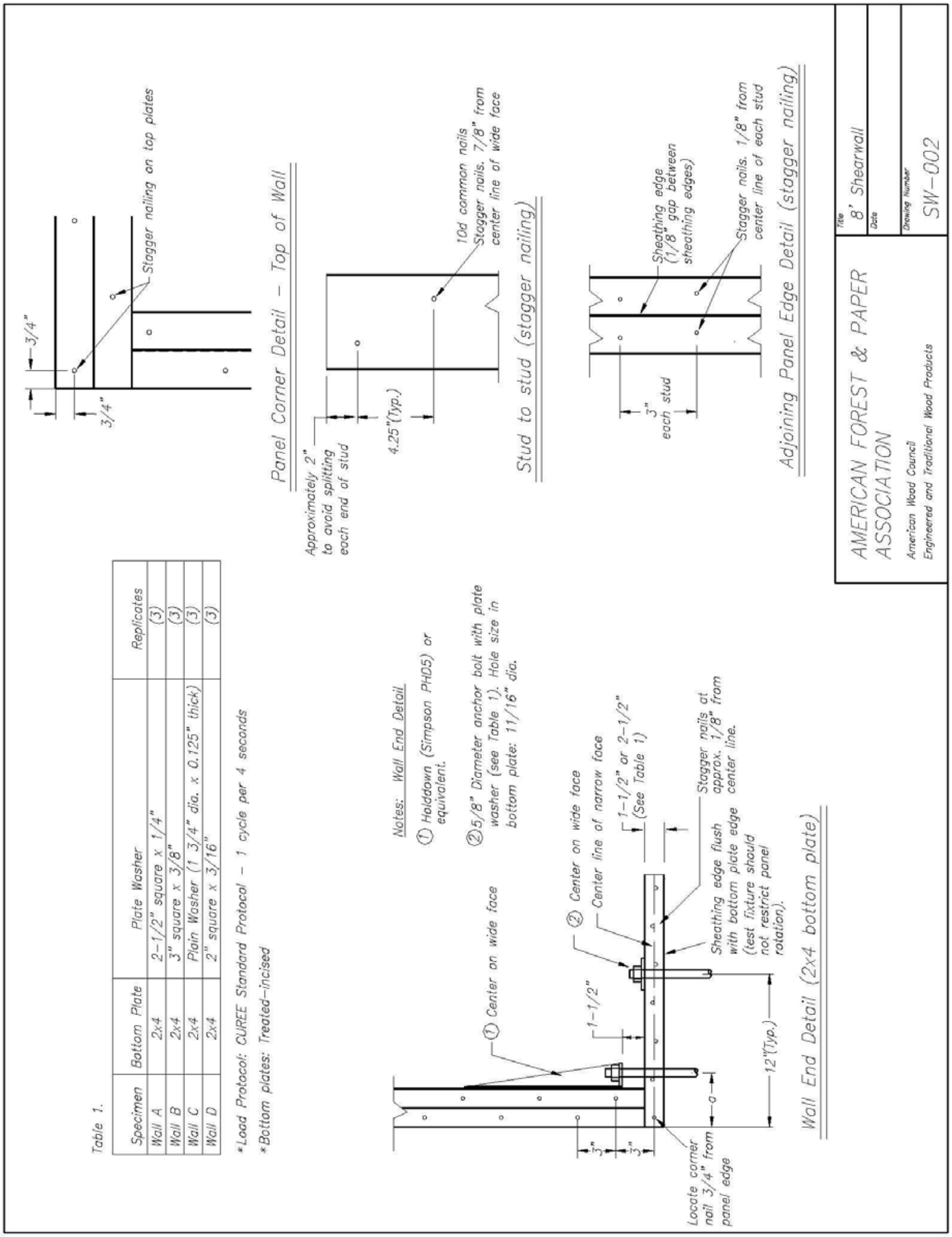
(continued on next page)

Summary Notes/Observations (continued):

Wall designation	Washer type	Notes/observations:	Dominant failure mode
D1	2 in. square plate washer	Edges of sheathing separated from studs. Small split in sole plate from sheathing nail pulling out. Little/no sole plate damage.	Fastener failure
D2		End stud separated from top plate. One edge of sheathing separated from stud. Little/no sole plate damage.	Fastener failure
D3		Middle stud had some splitting near sole plate. One edge of sheathing separated from stud. Little/no sole plate damage.	Fastener failure



Drawing A-1: Specifications for shearwall test specimen



Specimen	Bottom Plate	Plate Washer	Replicates
Wall A	2x4	2-1/2" square x 1/4"	(3)
Wall B	2x4	3" square x 3/8"	(3)
Wall C	2x4	Plain Washer (1 3/4" dia. x 0.125" thick)	(3)
Wall D	2x4	2" square x 3/16"	(3)

Drawing A-2: Specifications (cont'd.) for shearwall test specimen

Wall strength and anchorage calculations

1) ASD\LRFD Supplement, Special Design Provisions for Wind and Seismic

Nominal shear – wind: 1370 plf (Table 4.3A, Column B, footnote b)
Nominal shear – seismic: 980 plf (Table 4.3A, Column A, footnote b)
Allowable shear – seismic: 490 plf

Approximate wall strength: 1370 plf x 8 = 10,960 lbs

2) Tie–dwon device:

Nominal stength required: 1370 plf x 8.33' = 11,412 lbs
Allowable strength required: 490 plf x 8.33' = 4082 lbs

PHD5 – Avg. Ult Tensile Stength: 15,670 lbs
PDH5 – Allowable Design Strength: 4685 lbs

TR–12 Ult Stength (14) [Est. 0.242", 0.196"root, 90 ksi, 320ksi], 14 ga side member, G=0.5 main: 10,682 lbs

3) 5/8" diameter anchor bolts – shear:

2x4 bottom plate, G=0.50:
Nominal strength (TR–12): P = 3238 lbs (No. of Bolts: 1370 plf x 8'/3238 lbs = 3.38)
Allowable strength (NDS): Z' = 890 lbs x 1.6 = 1424 lbs (No. of Bolts: 490 plf x 8'/1424 lbs = 2.75)

3x4 bottom plate, G=0.50:
Nominal strength (TR–12): P = 4155 lbs (No. of Bolts: 1370 plf x 8'/4155 lbs = 2.64)
Allowable strength (NDS): Z' = 1140 lbs x 1.6 = 1824 lbs (No. of Bolts: 490 plf x 8'/1824 lbs = 2.15)

4) End posts:

Tension allowable capacity: 1.5 x 3.5 x 2 x 575 x 1.5 x 1.6 = 14,490 lbs
Compression perp. allowable capacity: 1.5 x 3.5 x 2 x 625 = 6562 lbs
Compression parallel allowable capacity: 2 x 1.5 x 3.5 x 1350 x 1.15 x 1.6 x 0.39 = 10,172 lbs

5) Stud to stud:

Stitch nail based on calculated allowable capacity (No penetration reduction): 490 x 8/(118 x 1.6) = (21) 10d common nails

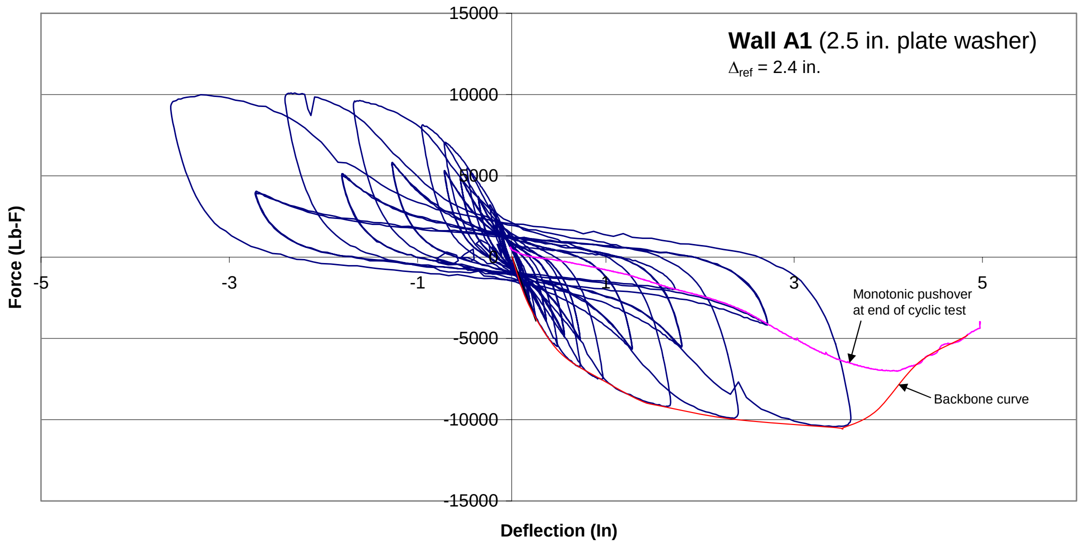
Stitch nail based on Ult. Capacity:
TR–12 Ult Capacity: 337 lbs per 10d common nail
Stitch nails required: 1370 plf x 8/(337) = (33) 10d common nails

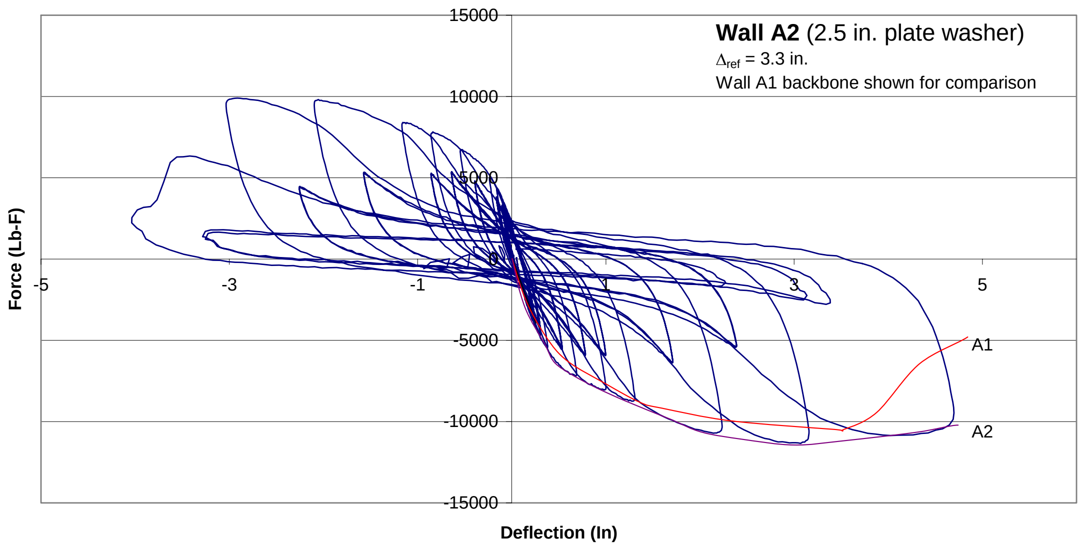
TR–12 Ult Capacity (sheathing to framing connection): 216 lbs per 8d common nail
Stitch nails required: 32 (216)/(337) = (21) 10d common nails

Note: 8d common (0.131" diameter x 2 1/2" long); 10d common (0.148" diameter x 3" long)

AMERICAN FOREST & PAPER ASSOCIATION	Title: 8' Shearwall
	Date:
American Wood Council Engineered and Traditional Wood Products	Drawing Number: SW–003

Drawing A-3: Calculations for shearwall test specimen





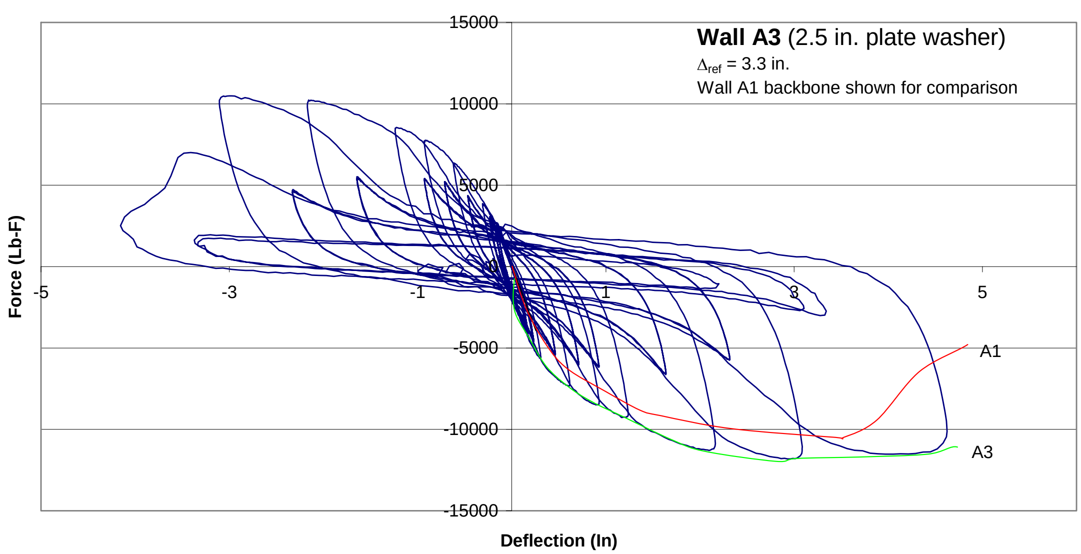


Figure 1. Hysteresis results for Walls A1-A3 (2.5 in. plate washer)

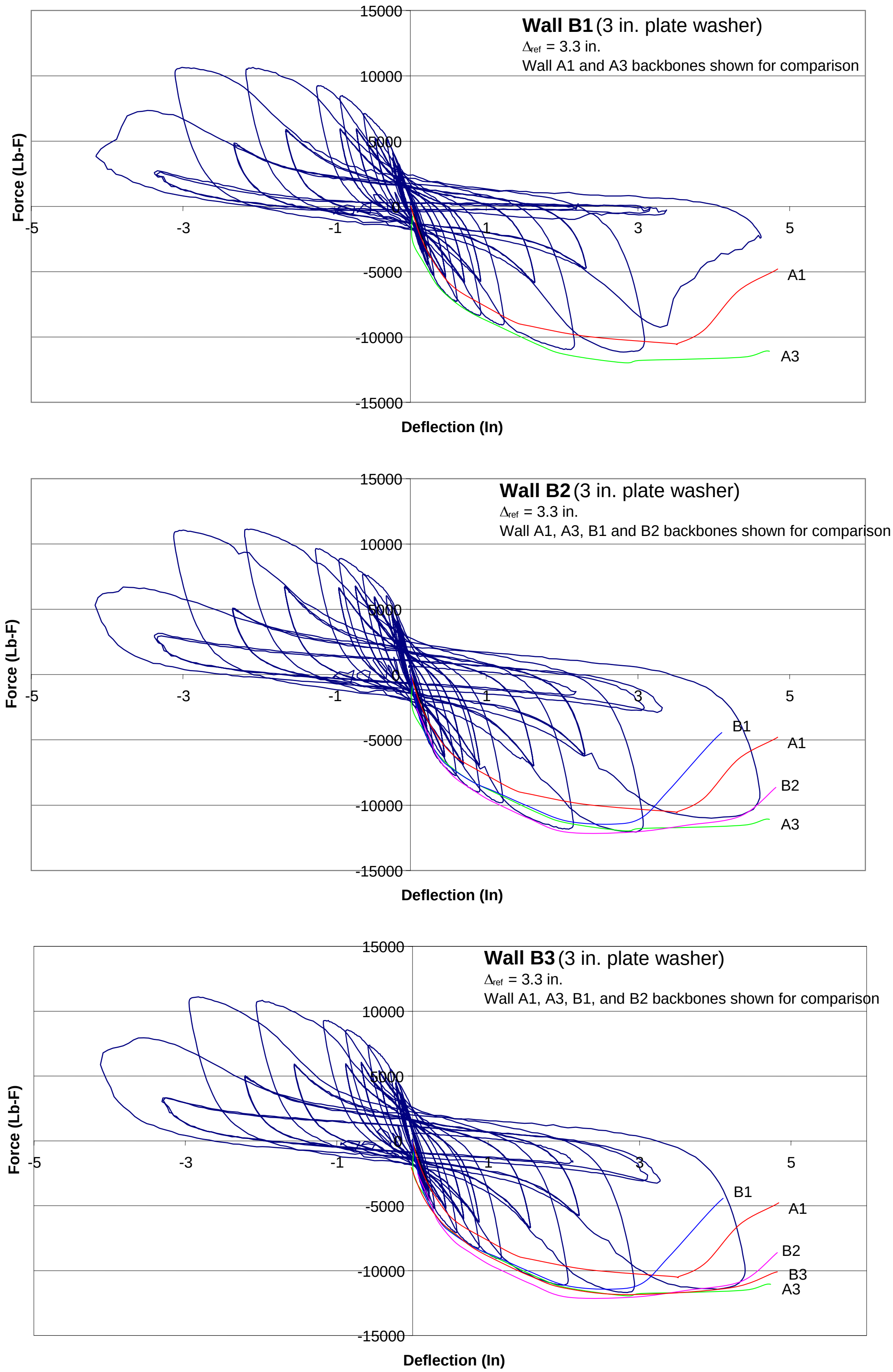
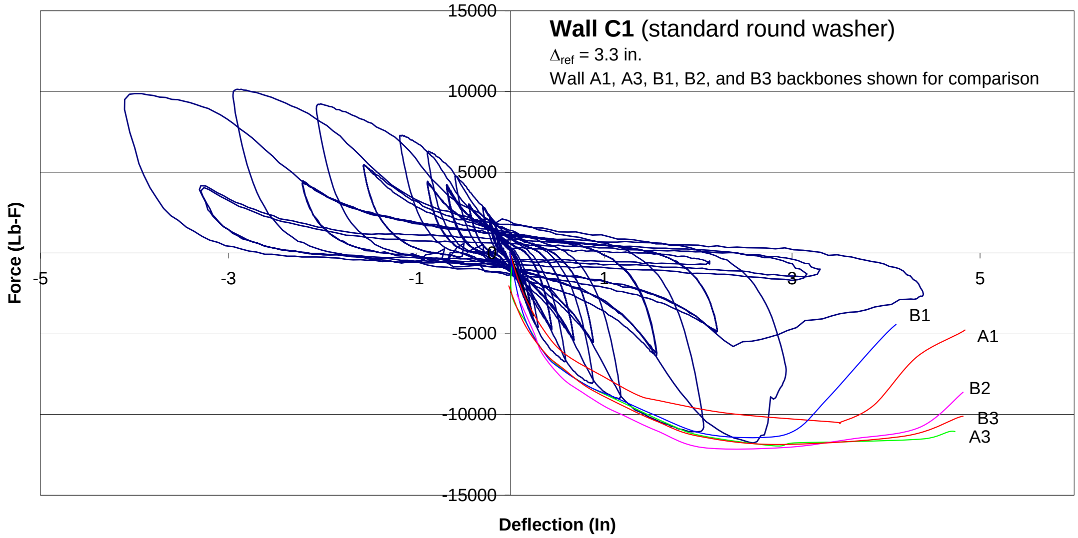
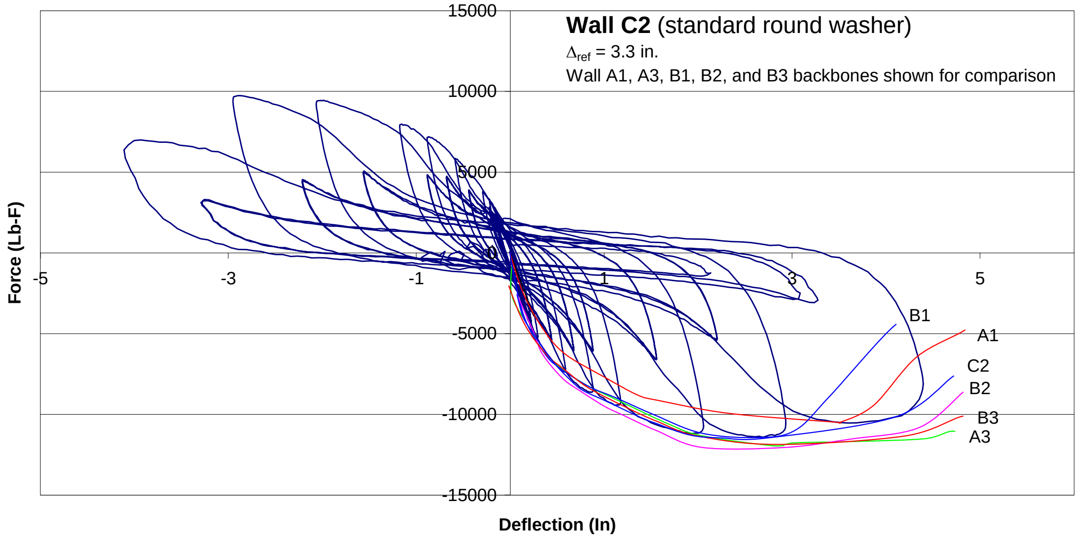


Figure 2. Hysteresis results for Walls B1-B3 (3 in. plate washer)





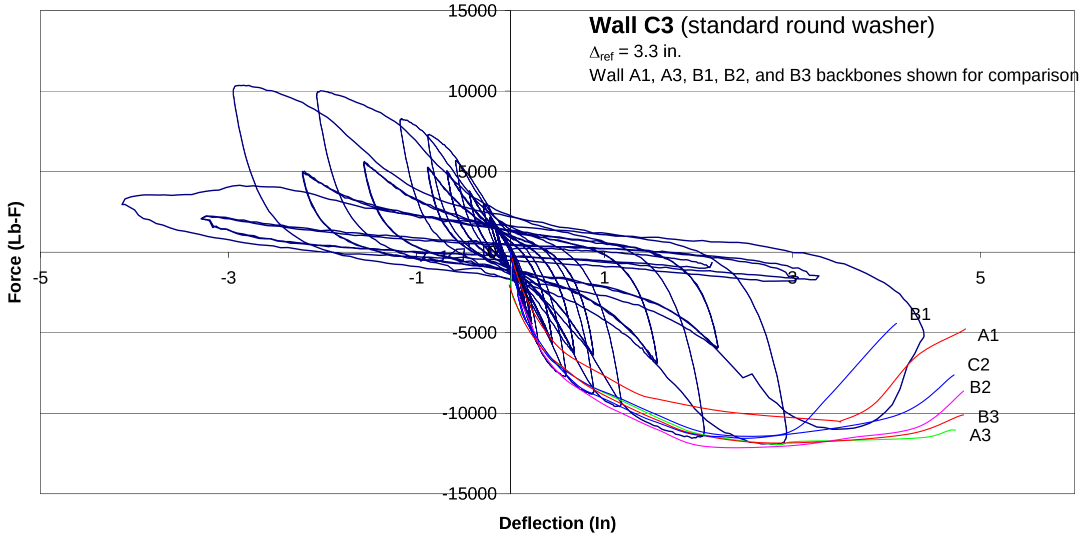
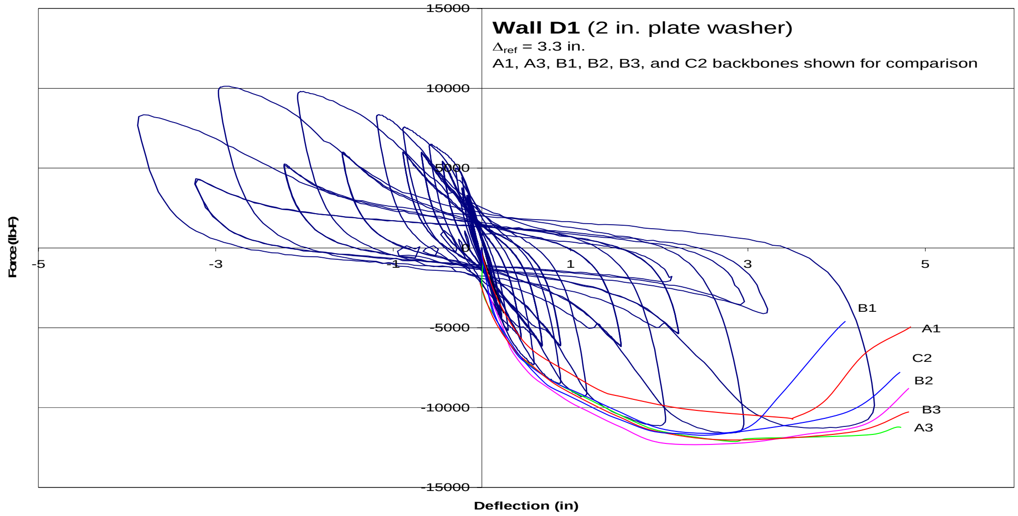
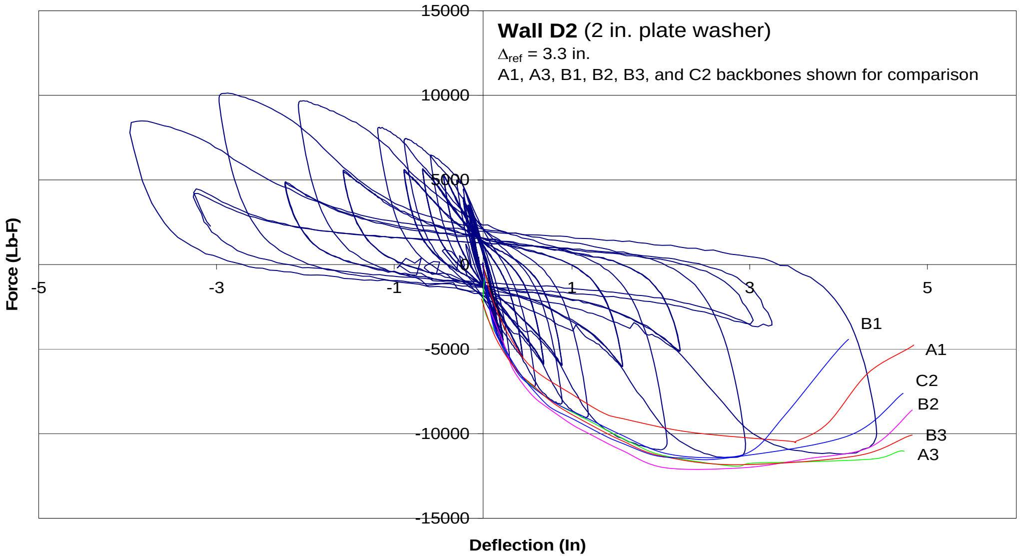


Figure 3. Hysteresis results for Walls C1-C3 (standard round washer)





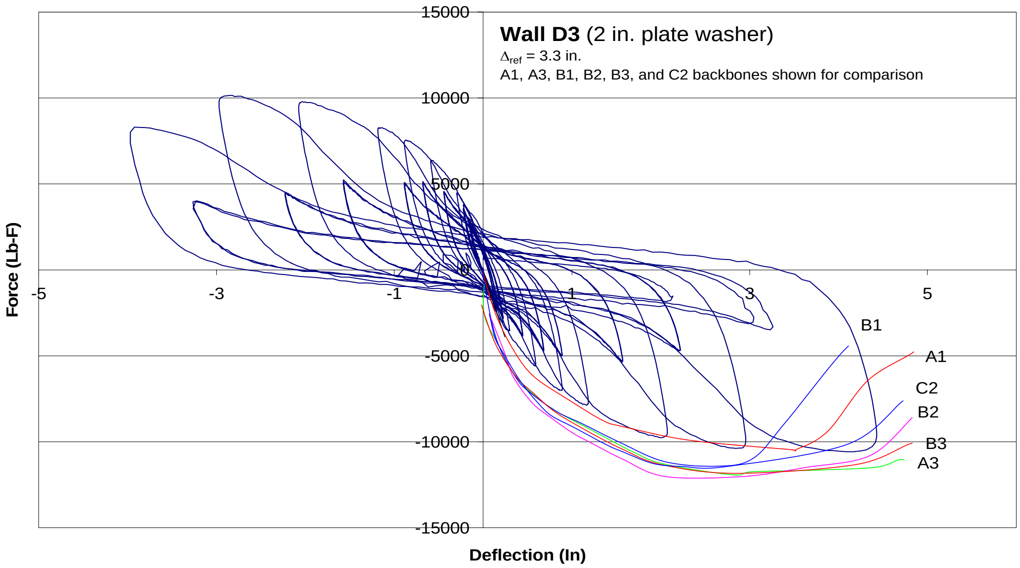


Figure 4. Hysteresis results for Walls D1-D3 (2 in. plate washer)

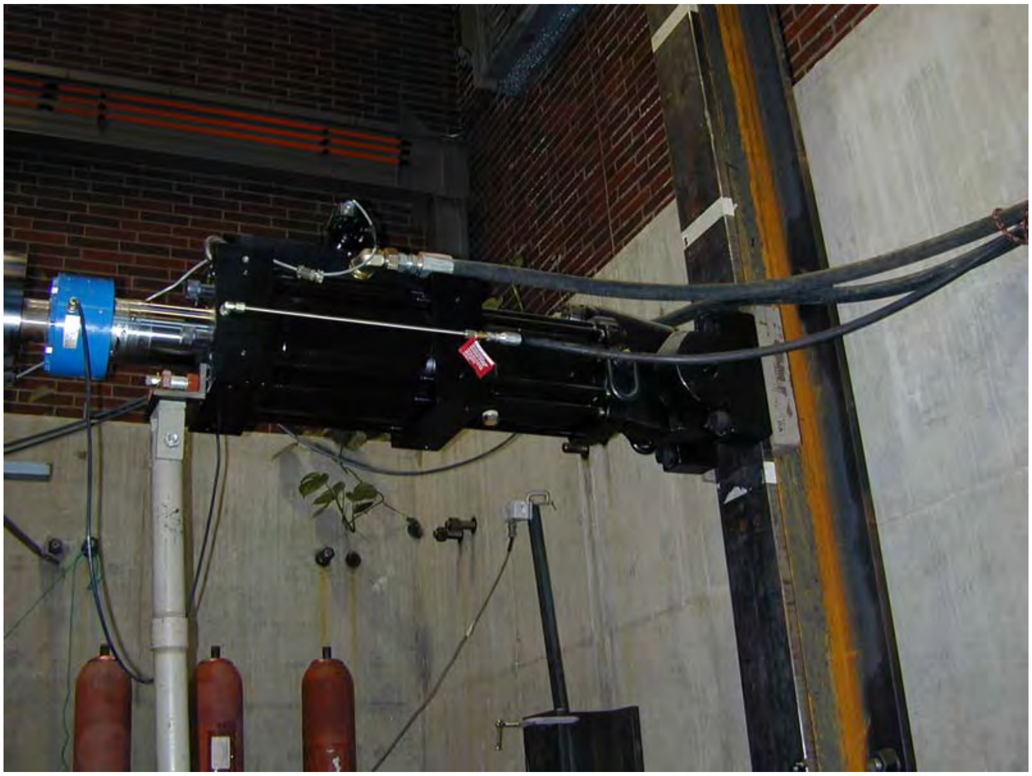


Figure 1. Hydraulic actuator located at top of wall

Figure 2. Shearwall assembly in test fixture

Figure 3. Shearwall assembly showing top loading beam and coupling to actuator

Figure 4. Hold-down in corner of shearwall

Figure 5. Fastener pull-out at panel edges along center stud (Specimen A1)

Figure 6. Uplift of sole plate at hold-down (Specimen A1)

Figure 7. Sheathing pull-away at corner (Specimen A1)

Figure 8. Sheathing edge pull-out (Specimen A2)

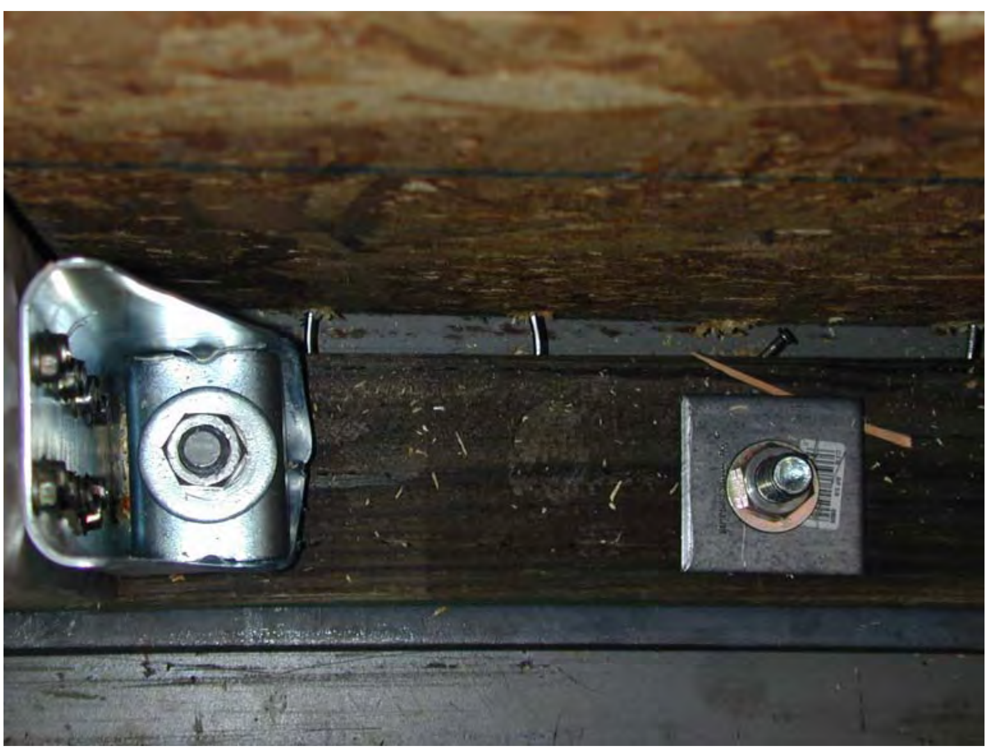


Figure 9. Sole plate after failure, no splitting (Specimen A2)

Figure 10. Fastener failure at sole plate, nail bending/ripping through sheathing (Specimen A3)

Figure 11. Failure at bottom of wall, some splitting of sole plate (Specimen A3)

Figure 12. Close-up of sole plate splitting (Specimen A3)

Figure 13. End stud failure at hold-down (Specimen B1)

Figure 14. Failure showing split at end of sole plate (Specimen B1)

Figure 15. End stud failure (Specimen B1)

Figure 16. Multiple failures, but no splitting of sole plate (Specimen B1)

Figure 17. Start of a split in sole plate (Specimen C1)

Figure 18. Sole plate splitting at hold-down (Specimen C1)

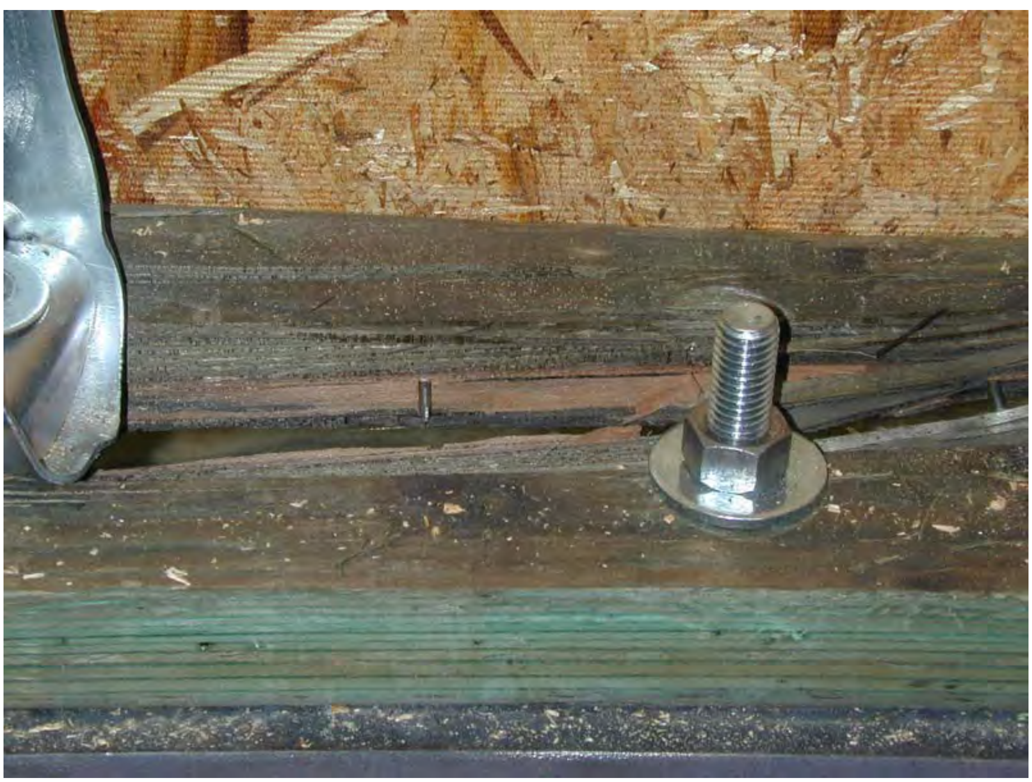


Figure 19. Sole plate splitting from hold-down to first washer location; no bending of washer (Specimen C1)

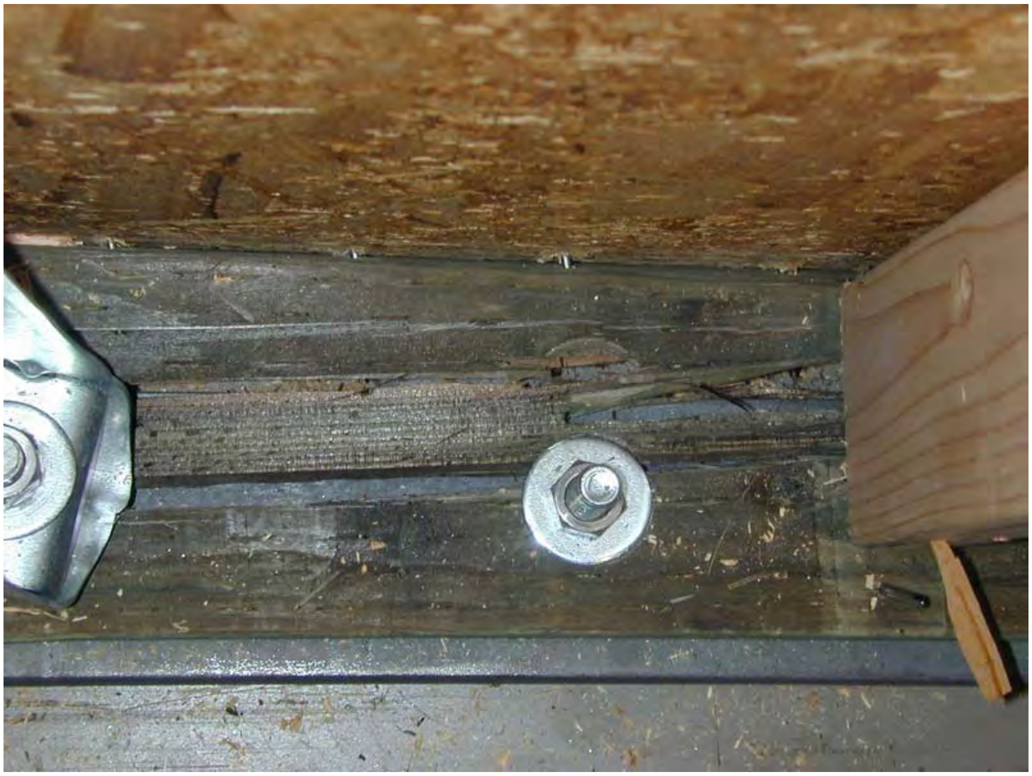


Figure 20. Top view of sole plate splitting from hold-down to first washer (Specimen C1)

Figure 21. End stud and sole plate failures (Specimen C1)

Figure 22. Sole plate split along its length (Specimen C1)

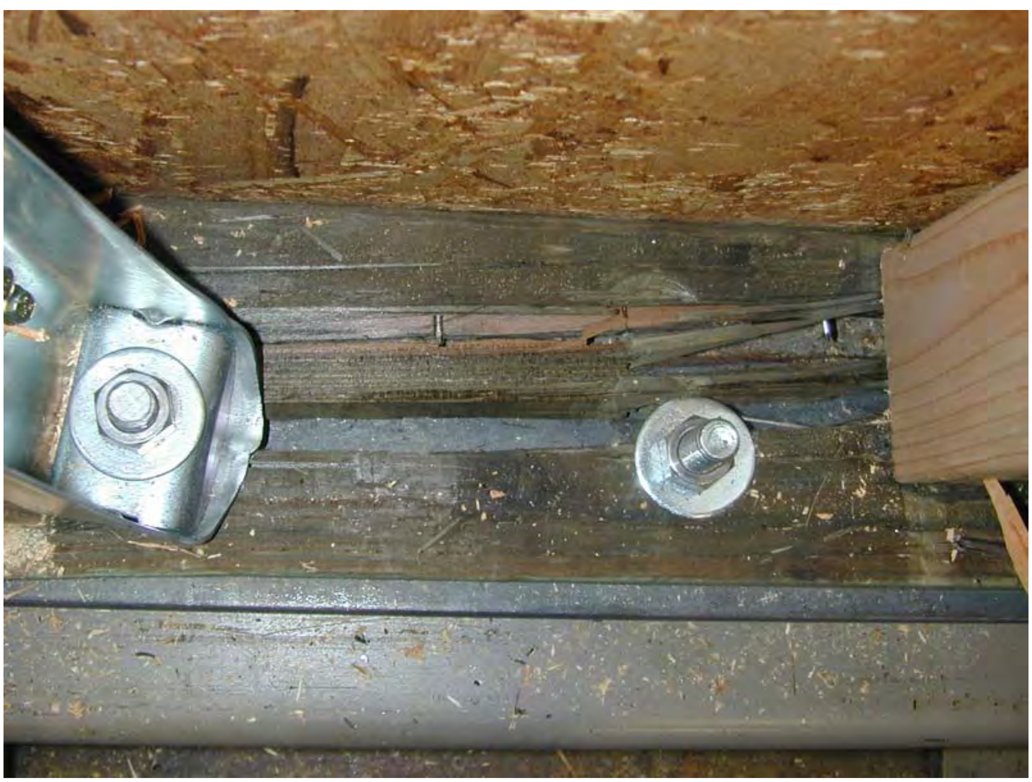


Figure 23. Multiple slits at sole plate (Specimen C1)

Figure 24. Sole plate split between interior studs (Specimen C1)

Figure 25. Sole plate split through interior bolt location (Specimen C1)

Figure 26. Failure at end of wall showing sole plate splitting (Specimen C2)

Figure 27. Anchor bolt showing slight embedment (but no bending) of washer (Specimen C3)

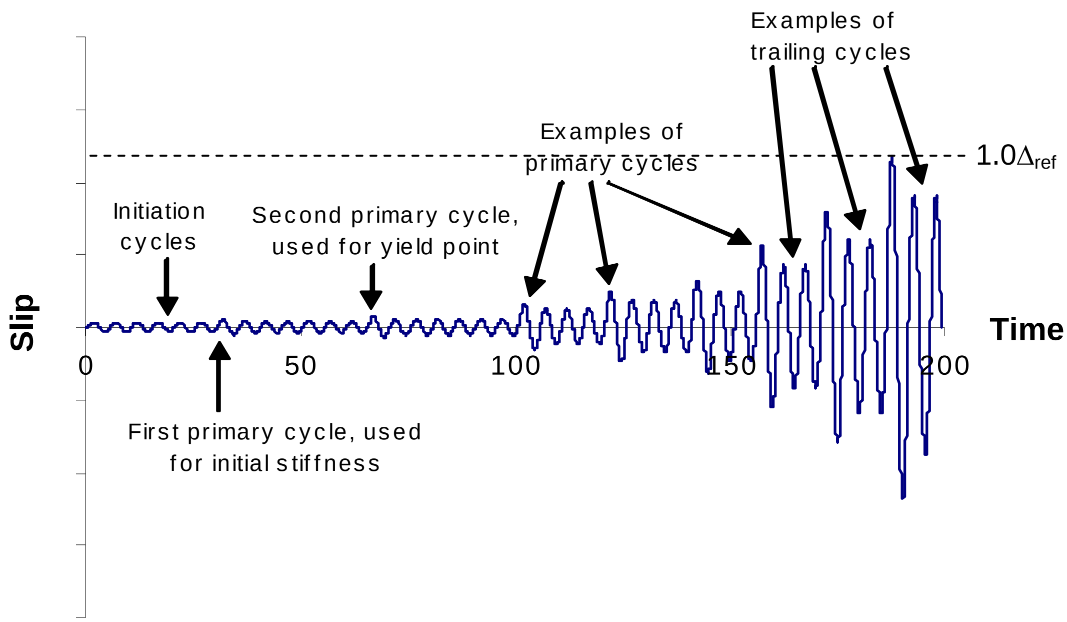
Figure 28. Sole plate (post-test) showing washer embedment (Specimen C2)

Figure 29. Sole plate (post-test) showing slight washer embedment (Specimen D2)

Figure 30. Sheathing separation from framing (Specimen D2)

Figure 31. Sheathing separation from bottom plate, showing bolted anchor and hold-down (Specimen D3)

APPENDIX A: CUREE Cyclic Loading Protocol



Technical Reference:

Krawinkler, H., Parisi, F., Ibarra, L., Ayoub, A. and Medina, R. (2000), "Development of a Testing Protocol for Wood Frame Structures," CUREE Publication No. W-02, Consortium of Universities for Research in Earthquake Engineering, Richmond, CA.