Cyclic tests\(^1\) of engineered shearwalls considering different plate washer sizes

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

Prepared by: David Rosowsky, Lori Elkins, and Cameron Carroll
Oregon State University
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Summary Table

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

\(A\): 2.5 in. square \(\times \) 1/4 in. plate washer
\(B\): 3 in. square \(\times \) 3/8 in. plate washer
\(C\): standard round washer (1.75 in. diam. \(\times \) 1/8 in.)
\(D\): 2 in. square \(\times \) 3/16 in. plate washer (tested March 2004)

Note: washers tightened to approximately 40 ft-lbs torque

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 \(P_{\text{max}}\)) were found to have no statistical differences at the 2% significance level.
## Summary Notes/Observations:

<table>
<thead>
<tr>
<th>Wall designation</th>
<th>Washer type</th>
<th>Notes/observations:</th>
<th>Dominant failure mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td></td>
<td>Sheathing separated from studs at center of wall.</td>
<td>Fastener failure</td>
</tr>
<tr>
<td>A2</td>
<td>2.5 in. square plate washer</td>
<td>Interior studs separated from sole plate. Sheathing separated from studs at center of the wall.</td>
<td>Fastener failure</td>
</tr>
<tr>
<td>A3</td>
<td></td>
<td>Same as A2 (with some splitting of sole plate).</td>
<td>Fastener failure</td>
</tr>
<tr>
<td>B1</td>
<td></td>
<td>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.</td>
<td>Fastener failure</td>
</tr>
<tr>
<td>B2</td>
<td>3 in. square plate washer</td>
<td>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.</td>
<td>Fastener failure</td>
</tr>
<tr>
<td>B3</td>
<td></td>
<td>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.</td>
<td>Fastener failure</td>
</tr>
<tr>
<td>C1</td>
<td></td>
<td>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.</td>
<td>Sole plate failure (splitting)</td>
</tr>
<tr>
<td>C2</td>
<td>standard round washer</td>
<td>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.</td>
<td>Sole plate failure (splitting)</td>
</tr>
<tr>
<td>C3</td>
<td></td>
<td>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.</td>
<td>Sole plate failure (splitting)</td>
</tr>
</tbody>
</table>
Summary Notes/Observations (continued):

<table>
<thead>
<tr>
<th>Wall designation</th>
<th>Washer type</th>
<th>Notes/observations:</th>
<th>Dominant failure mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1</td>
<td></td>
<td>Edges of sheathing separated from studs. Small split in sole plate from sheathing nail pulling out. Little/no sole plate damage.</td>
<td>Fastener failure</td>
</tr>
<tr>
<td>D2</td>
<td>2 in. square plate washer</td>
<td>End stud separated from top plate. One edge of sheathing separated from stud. Little/no sole plate damage.</td>
<td>Fastener failure</td>
</tr>
<tr>
<td>D3</td>
<td></td>
<td>Middle stud had some splitting near sole plate. One edge of sheathing separated from stud. Little/no sole plate damage.</td>
<td>Fastener failure</td>
</tr>
</tbody>
</table>
Wall Construction:
1) Studs and top plates: 2x4 Douglas Fir.
2) Bottom plate: See Table 1.
3) Framing attachment:
   Plate to plate: (2) 16d common per foot
   Plate to stud: (2) 16d common each end
   Stud to stud: (2) 10d common per 8.5 inches
   (Stud to stud at adj. panel edge: 21 nails total)
   End studs: Avoid nailing in hold-down region
4) Sheathing: 7/16" OSB per US Code PS-2
5) Sheathing attachment: 8d common wire nail (0.131" diameter x 2 1/2" long)
   3" e.o. edge, 12" e.o. field

Notes:
16d common: 0.162" dia. x 3 1/2" long
10d common: 0.148" dia. x 3" long
8d common: 0.131" dia. x 2 1/2" long
Drawing A-2: Specifications (cont’d.) for shearwall test specimen
Dial strength and anchorage calculations:

1. ASDD/AFCI Supplement. Special Design Provisions for Metal and Wood
   Frame shear ~ direct: 1.370 psf (Table A.3, Column 6, Reference b)
   Allanwood shear ~ direct: 1.080 psf (Table A.3, Column 4, Reference b)
   Approximate total design shear: 1.080 psf x 2 = 2.160 psi

2. Tie-down devices:
   Permanent strength required: 1270 psf x 3.33 = 4215 lbs
   Allowable strength required: 401 psi x 3.33 = 1340 lbs
   Two 16" x 75" connector plates, 4.56 kips (10,080 lbs x 16"")

3. 3/4" diameter anchor bolts ~ shear:
   2" diameter plate: 0.363
   
   \( P = \frac{2.28.84}{150} \) (lbs. of bolts)
   Allowable strength (FOS): \( P = \frac{1120}{150} \) lbs. = 7.46 lbs

5. 1/2" diameter plate: 0.195
   
   \( P = \frac{4415}{5} \) (lbs. of bolts)
   Allowable strength (FOS): \( P = \frac{1110}{150} \) lbs. = 7.40 lbs

4. End plate:
   Tension allowable capacity: 1.5 x 3.5 x 2 x 0.75 = 33.75 lbs
   Compression allowable capacity: 1.5 x 3.5 x 2 x 0.75 = 33.75 lbs
   Compression parallel allowable capacity: 1.5 x 3.5 x 3 = 1368 x 1.75 x 1.76 x 0.75 = 13,712 lbs

5. Stud to stud:
   20ths net area on opposite stud face (62 penetration reduction) = \( 0.8 \times (0.75 = (2.5), 100 common nails)
   neglect end nailing
   19-12 LF. Capacity: 258 lbs per 100 common nails
   19-12 LF. Capacity (nailing in framing connections): 218 lbs per 100 common nails
   Block nails required: \( 27 \times (150) = 4050 \) common nails
   Notes:
   8d common (0.14" diameter x 2, 1/4" long), 8d common (0.148" diameter x 3"") long

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**AMERICAN FOREST & PAPER ASSOCIATION**

*American Wood Council*

engined test fuecles and products

**3rd Shearwll**

Steve Raue

SWM-003

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**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:**