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

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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>Avg. A</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>Avg. A (excl. A1)</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>Avg. B</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>Avg. C</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>Avg. D</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>

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

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\(^2\).

\(^1\) 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>
Drawing A-1: Specifications for shearwall test specimen
Table 1.

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Bottom Plate</th>
<th>Plate Washer</th>
<th>Replicates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall A</td>
<td>2x4</td>
<td>2-1/2” square x 1/4”</td>
<td>(3)</td>
</tr>
<tr>
<td>Wall B</td>
<td>2x4</td>
<td>3” square x 3/8”</td>
<td>(3)</td>
</tr>
<tr>
<td>Wall C</td>
<td>2x4</td>
<td>Plain Washer (1 3/8” dia., x 0.125” thick)</td>
<td>(3)</td>
</tr>
<tr>
<td>Wall D</td>
<td>2x4</td>
<td>2” square x 5/16”</td>
<td>(3)</td>
</tr>
</tbody>
</table>

*Load Protocol: CUREE Standard Protocol – 1 cycle per 4 seconds
*Bottom plates: Treated-inciised

Notes: Wall End Detail
① Holdown ( Simpson PM25) or equivalent.
② 5/8” Diameter anchor bolt with plate washer (see Table 1). Hole size in bottom plate 11/16” dia.

Panel Corner Detail - Top of Wall

Approximately 3”
To avoid splitting each end of stud

4.25” (typ.)

10d common nails
Stagger nails, 7/8” from center line of wide face

Stud to stud (stagger nailing)

Locate corner nail 3/4” from panel edge

Adjoining Panel Edge Detail (stagger nailing)

Sheathing edge (1/8” gap between sheathing edges)

Stagger nails, 1/8” from center line of each stud

Stagger nails at approx. 1/8” from center line.

Sheathing edge flush with bottom plate edge (test fixture should not restrict panel rotation).

1”-1/2” or 2-1/2” (See Table 1)

Center line of narrow face

Center on wide face

Center on wide face

12” (typ.)
Flat strength and anchorage calculations

1) ASD/AISC Supplement; Special Design Provisions for Wind and Seismic

   (a) Dead load: 1,370 psi (Table A-34, Column 4, Thisina's)
   (b) Live load: 480 psi (Table A-34, Column 4, Thisina's)

   Approximate wind load: 1370 psi x 8 = 10,960 lbs

2) Seismic loads:

   (a) Push/reverse direction:

   Permanent load required: 1,720 psi x 0.833 = 1,440 lbs
   Ultimate strength required: 480 psi x 0.833 = 400 lbs

   (b) Pull direction:

   Ultimate strength required: 480 psi x 0.833 = 400 lbs
   Permanent load required: 1,720 psi x 0.833 = 1,440 lbs

3) N/W diameter anchor bolts - shear:

   Bolt shear capacity: 1.3 x 3.5 x 3 = 425 kips
   Bolt shear capacity: 1.3 x 1.6 = 212 kips
   Allowable shear capacity: 212 kips
   Allowable shear capacity: 425 kips

4) End plates:

   Tension allowable capacity: 1.3 x 3.5 x 3 = 16.4 kips
   Bolt shear capacity: 212 kips
   Compression allowable failure capacity: 1.3 x 1.6 = 212 kips
   Compression allowable failure capacity: 16.4 kips

5) Stud to wall:

   Stud shear strength: 480 psi x 0.75 x 0.4 = 180 kips
   Stud shear strength: 180 kips
   Stud shear strength: 480 psi x 0.75 x 0.4 = 180 kips
   Stud shear strength: 180 kips

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)
Wall C1 (standard round washer)
Δ_{ref} = 3.3 in.
Wall A1, A3, B1, B2, and B3 backbones shown for comparison

Wall C2 (standard round washer)
Δ_{ref} = 3.3 in.
Wall A1, A3, B1, B2, and B3 backbones shown for comparison

Wall C3 (standard round washer)
Δ_{ref} = 3.3 in.
Wall A1, A3, B1, B2, and B3 backbones shown for comparison

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

Examples of primary cycles

Examples of trailing cycles

First primary cycle, used for initial stiffness

Second primary cycle, used for yield point

Technical Reference: