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COMBINED SHEAR AND WIND UPLIFT RESISTANCE OF WOOD STRUCTURAL PANEL SHEARWALLS

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Abstract

Shearwalls constructed with wood structural panels, such as plywood and oriented strand board (OSB), have been used to resist combined shear and wind uplift forces for many years in the U.S. For example, the Southern Building Code Congress International (SBCCI) published SSTD 10, *Standard for Hurricane Resistant Residential Construction*, in 1999, which provided the shear resistance table for wood structural panels. When wood structural panels are used in combined shear and wind uplift, SSTD 10-99 also tabulated the wind uplift resistance of wood structural panels with a minimum thickness of 12 mm (15/32 in.) when used in conjunction with the shear resistance table.

Working with researchers at the National Home Builders Association Research Center (NAHB RC), Norbord Industries sponsored full-scale combined shear and uplift tests, showing that the cross-grain bending of the bottom plate, which is a brittle failure mode, could be avoided by using 5.8 x 76 x 76 mm (0.229 x 3 x 3 in.) plate washers with anchor bolts. The NAHB RC tests were conducted in lateral shear and tension (uplift) separately, and the effect of combined shear and uplift was evaluated based on an engineering analysis.

After reviewing the NAHB RC study, APA and Norbord jointly conducted full-scale combined shear and wind uplift tests at Clemson University to gather more data on this subject. The test setup at Clemson University was capable of increasing the shear and wind uplift forces simultaneously until failure was reached by using a pulley system controlling the bi-axial forces in both lateral and vertical directions. Results of the Clemson study were used to support the development of engineering standards and changes to the national building code in the U.S., and are reported in this paper.

In 2007, APA constructed new combined shear and wind uplift test equipment that is capable of bi-axial loading in both lateral and vertical directions with independent but synchronized loading mechanisms. The vertical load can be applied as either an uplift force or a downward gravity load. Research results using this new equipment are utilized to enhance the understanding of the design on the bi-axial combined shear and wind uplift. This paper describes the latest finding from this research.

1. Introduction

Wood structural panels, by definition of the U.S. International Building Code (IBC) [1] and International Residential Code (IRC) [2], include plywood manufactured in accordance with Voluntary Product Standard PS1, *Structural Plywood* [3], and oriented strand boards (OSB) and plywood manufactured in accordance with Voluntary Product Standard PS2, *Performance Standard for Wood-Based Structural-Use Panels* [4]. While most wood structural panels are specified based on their span rating, the mechanical properties of wood structural panels are published by APA – The Engineered Wood Association in the *Panel Design Specification* [5]. When used as a lateral force resisting element, wood structural panels can be designed in accordance with the shearwall design values established by APA and published in the IBC.

Most buildings subjected to lateral forces from wind are usually subjected to simultaneous wind uplift forces. Shearwalls constructed with wood structural panels have been used to resist combined shear and wind uplift forces for years in the U.S. For example, the Southern Building Code Congress International (SBCCI) published SSTD 10, *Standard for Hurricane Resistant Residential Construction* [6], in 1999, which provided not only the shear resistance, but also the wind uplift resistance of wood structural panels. When wood structural panels are designed to resist combined shear and wind uplift forces, SSTD 10-99 tabulated the wind uplift resistance of wood structural panels with a minimum thickness of 12 mm (15/32 inch) when used in conjunction with the shear resistance table.

The SSTD 10 wind uplift table was developed based on the principle of engineering mechanics. It assumes that the nails installed in the shearwall assembly are used primarily to resist the lateral shear forces. If there are extra nails that are beyond the demand for the lateral shear resistance, they can be used to resist wind uplift forces. The through-the-thickness shear and tensile strength of the sheathing are checked, but they do not govern the capacity of the wall. While this principle seems straightforward, a major concern in this application is the possible cross-grain bending of the bottom wall plate due to the non-concentric uplift forces acting on one face of the wall. This cross-grain bending can split the bottom plate, usually 2x4 lumber, and the design value for this property is unavailable in the code. Therefore, a practical solution to avoid this failure mode is to specify anchor bolts at a tight spacing with plate washers that are thick and wide enough to hold the bottom plate in place without inducing splitting.

Due to the merge of three regional U.S. model building codes into the IBC in 2000, SBCCI was no longer in existence as an organization and SSTD 10 has not been maintained. In 2005, the Institute for Business & Home Safety (IBHS) published the *Guidelines for Hurricane Resistant Residential Construction* [7] based on SSTD 10. In the meantime, the International Code Council (ICC) is developing ICC 600, *Standards for Residential Construction in High Wind Regions* [8] and the American Forest & Paper Association (AF&PA) is also revising the 2005 ANSI/AF&PA *Special Design Provisions for Wind and Seismic* (SDPWS) [9]. All of the referenced standards mentioned above contain provisions for combined shear and wind uplift using wood structural panels. The SDPWS revisions include the re-calculation of the mechanics-based uplift resistance using the nail yield model, as given in the 2005 *National Design Specification for Wood Construction* (NDS) [10].

In support of these code and standard development activities, APA and its members, specifically Norbord Industries, conducted full-scale combined shear and uplift tests at Clemson University in 2006. An additional series of tests were conducted at the APA Research Center, Tacoma, Washington, in 2008. This paper provides results and analyses from those tests.

2. Materials and Test Methods

2.1 Material Description

The full-scale tests conducted at Clemson University in 2006 were largely designed to address the concern of cross-grain bending of the bottom wall plate. In a previous pilot study conducted by the National Home Builders Association Research Center (NAHB RC) [12] in 2005, it was shown that the cross-grain bending of the bottom plate could be avoided by using 5.8 x 76 x 76-mm (0.229 x 3 x 3-in.) plate washers with 15.9-mm (5/8-in.) diameter anchor bolts spaced at 406 mm (16 in.) on center. However, the NAHB RC study was conducted in lateral shear and tension (pure uplift) separately, and the effect of combined shear and uplift was evaluated based on an engineering analysis. The Clemson study was conducted in full-scale to apply the shear and uplift forces simultaneously so that the ultimate shear and uplift forces could be reached approximately at the same time.

A total of seven full-scale walls were tested at Clemson University using 11-mm (7/16-in.) commodity OSB sheathing (rated Wall 24) supplied by Norbord Industries. Due to the length limitation of this paper, only one typical framing detail (for Walls 4a and 4b) is shown in Appendix A. The framing materials (2x4 No. 2 spruce-pine-fir) were purchased from a local lumber yard by Clemson University with an estimated moisture content of 16% or higher. The holdowns were ordered from Simpson Strong-Tie. Most test assemblies were constructed by Clemson's students with very limited wall framing experience and therefore the workmanship was expected to represent the lower end of construction practice. Other test details are summarized in Table 1 and below.

Table 1. Summary of test assemblies conducted at Clemson University [a]

Wall ID	Nail spacing [b]	Holddown	Plate washer	Uplift	Shear
1a	152&305 mm (6&12 in.)	Yes	3.2 x 76 x 76 mm (0.125 x 3 x 3 in.)	x	NA
1b	152&305 mm (6&12 in.)	No	5.8 x 76 x 76 mm (0.229 x 3 x 3 in.)	x	NA
2	152&305 mm (6&12 in.)	Yes	3.2 x 76 x 76 mm (0.125 x 3 x 3 in.)	NA	x
3a	152&305 mm (6&12 in.)	Yes	3.2 x 76 x 76 mm (0.125 x 3 x 3 in.)	x	x
3b	152&305 mm (6&12 in.)	Yes	5.8 x 76 x 76 mm (0.229 x 3 x 3 in.)	x	x
4a	102&305 mm (4&12 in.)	Yes	5.8 x 76 x 76 mm (0.229 x 3 x 3 in.)	x	x
4b	102&305 mm (4&12 in.)	Yes	5.8 x 76 x 76 mm (0.229 x 3 x 3 in.)	x	x

[a] See below for more detailed information.
[b] 8d common nails (3.3 x 64 mm or 0.131 x 2-1/2 in.).

- Framing – 2 x 4 No. 2 spruce-pine-fir studs at 406 mm (16 in.) o.c. with a single 2x4 center stud.
- Sheathing – Two 11-mm (7/16-in.) Wall-24 OSB panels 1219 x 2438 mm (4 x 8 ft) applied vertically.
- Fasteners – 8d common nails (3.3 x 64 mm or 0.131 x 2-1/2 in.).
- Nailing Pattern – A single row of 8d nails at 152 mm (6 in.) or 102 mm (4 in.) o.c. on panel sides (vertical edges) with a 9.5 mm (3/8 in.) edge distance and double rows of 8d nails at 76 mm (3 in.) o.c. along top and bottom plates (horizontal edges) with a 13 mm (1/2 in.) edge distance. A 305 mm (12 in.) o.c. nailing in the field of panel.
- Holddown (when used) – Holddown has a 17.4 kN (3,920 lbf) design capacity and is attached with 6.4 x 76 mm (1/4 x 3 in.) SDS screws. The holddown bolts were installed wrench-tight.

- Anchor Bolts – 16-mm (5/8-in.) -dia. bolts with 3.2 x 76 x 76 mm (0.125 x 3 x 3 in.) or 5.8 x 76 x 76 mm (0.229 x 3 x 3 in.) plate washers at 406 mm (16 in.) o.c. The anchor bolts were installed wrench-tight.

For the full-scale tests conducted at APA in 2008, the objective was to confirm the design values with 10d common (3.8 x 76 mm or 0.148 x 3 in.) nails using 12-mm (15/32-in.) commodity OSB Structural I sheathing (rated 32/16), which were not previously tested at Clemson University and represent the highest design capacities proposed for the adoption into SDPWS. A total of six full-scale walls were tested at APA using OSB sheathing purchased from a local lumber yard along with framing materials (2x4 No. 2 Douglas-fir) with an estimated moisture content of 16% or higher. The holdowns were manufactured by Simpson Strong-Tie. Other test details are summarized in Table 2 and below.

Table 2. Summary of test assemblies conducted at APA [a]

Wall ID	Nail spacing [b]	Holddown	Plate washer	Uplift	Shear
A1	152&305 mm (6&12 in.)	Yes	5.8 x 76 x 76 mm (0.229 x 3 x 3 in.)	x	–
A2				x	–
A3				–	x
A4				x	x
A5				x	x
A6				x	X

[a] See below for more detailed information.
[b] 10d common nails (3.8 x 76 mm or 0.148 x 3 in.).

- Framing – 2 x 4 No. 2 Douglas-fir at 406 mm (16 in.) o.c. with a single 2x4 center stud.
- Sheathing – Two 12-mm (15/32-in.) 32/16 OSB panels 1219 x 2438 mm (4 x 8 ft) applied vertically.
- Fasteners – 10d common nails (3.8 x 76 mm or 0.148 x 3 in.).
- Nailing Pattern – A single row of 10d nails at 152 mm (6 in.) o.c. on panel sides (vertical edges) with a 9.5 mm (3/8 in.) edge distance and double rows of 10d nails at 76 mm (3 in.) o.c. along top and bottom plates (horizontal edges) with a 13 mm (1/2 in.) edge distance. A 305 mm (12 in.) o.c. nailing in the field of panel.
- Holddown – Holddown has a 21.4 kN (4,800 lbf) design capacity and is attached with 6.4 x 76 mm (1/4 x 3 in.) SDS screws. The holddown bolts were installed finger-tight + 1/8 turn except for Wall A6, which was wrench-tight.
- Anchor Bolts – 12.7-mm (1/2-in.) -dia. bolts with 5.8 x 76 x 76 mm (0.229 x 3 x 3 in.) plate washers at 406 mm (16 in.) o.c. The anchor bolts were installed finger-tight + 1/8 turn except for Wall A6, which was wrench-tight.

2.2 Test Methods

The Clemson test setup, as shown in Figure 1, was capable of increasing the shear and wind uplift forces simultaneously until failure was reached by using a pulley system controlling the bi-axial forces in both lateral and vertical directions. The APA setup, as shown in Figure 2, is also capable of bi-axial loading, but using independent, synchronized loading systems to reach the ultimate shear and uplift loads at approximately the same time. The vertical load can be applied as either an uplift force or a downward gravity load. All tests were conducted monotonically at indoor environmental conditions.

Figure 1. Test setup at Clemson University

Figure 2. Test setup at APA

It should be noted that the Clemson tests were not necessarily conducted in the sequence shown in Table 1. For example, Walls 1a (uplift only) and 2 (shear only) were conducted first, followed by Wall 3a (combined shear and uplift with 3.2 x 76 x 76 mm or 0.125 x 3 x 3 in. plate washers). Due to an observed bending of the 3.2-mm (0.125-in.) plate washers on Wall 3a, which led to a cross-grain bending failure on the bottom wall plate, Walls 3b, 4a, and 4b were tested with 5.8 x 76 x 76-mm (0.229 x 3 x 3-in.) plate washers. Note that Wall 4b was a replicate of Wall 4a so as to gain more confidence in the test results for such a wall configuration. Wall 1b was conducted last to study the effect of holddown on the uplift-only capacity of the wall by comparing the results with Wall 1a. Both Walls 1a and 1b failed due to the nail withdrawal from the top plates and panel tear-out. The washer plates did not bend in either wall.

3. Results and Discussions

Based on the principle of mechanics, the capacities (allowable stress design) of walls for the combined shear and uplift can be calculated in accordance with NDS, as shown in Table 3.

Table 3. Wood Structural Panels for Combined Shear and Wind Uplift [a,b,c]

	Nail Spacing Required for Shearwall Design [d]											
	6d @ 152 & 305 mm			8d @ 152 & 305 mm			8d @ 102 & 305 mm			10d @ 152 & 305 mm		
	Alternate Nail Spacing at Top and Bottom Plate Edges (mm)											
	152	102	76	152	102	76	152	102	76	152	102	76
	Allowable Uplift Capacity (kN/m) [c]											
Nails-Single Row [e]	0.0	1.2	2.5	0.0	1.6	3.2	NP	0.0	1.6	0.0	1.9	3.8
Nails-Double Row [f]	2.5	4.9	7.4	3.2	6.3	**9.5**	1.6	4.7	**7.9**	3.8	7.6	**11.5**

[a] Minimum 11-mm (7/16-inch) OSB supported by vertical framing at 406 mm (16 in.) on center or less. The framing species shall have a published specific gravity of 0.42 (spruce-pine-fir) or greater.

[b] Anchor bolts shall be installed at 406 mm (16 in.) on center.

[c] For framing with a specific gravity of 0.49 or greater, divide uplift values listed in above table by 0.92.

[d] Where nail size is 6d or 8d, the tabulated uplift values are applicable to 11 mm (7/16 in.) minimum OSB panels. Where nail size is 10d, the tabulated uplift values are applicable to 12 mm (15/32 in.) minimum OSB.

[e] OSB panels shall overlap the top member of the double top plate and bottom plate by 38 mm (1-1/2 in.) and a single row of fasteners shall be placed 19 mm (3/4 in.) from the panel edge.

[f] OSB panels shall overlap the top member of the double top plate and bottom plate by 38 mm (1-1/2 in.). Rows of fasteners shall be 13 mm (1/2 in.) apart with a minimum edge distance of 13 mm (1/2 in.). Each row shall have nails at the specified spacing.

Results from Clemson and APA tests are shown in Tables 4 and 5, respectively. The tables also include the ratio of applied uplift and shear loads, which was intended to cover a range of ratios based on Table 3. It should be noted that since the APA tests were conducted using Douglas-fir framing, the tabulated uplift design value shown in Table 5 for the assembly configuration (10d @ 152 & 305 mm with double row of nails at 76 mm) was calculated by dividing the tabulated value of 11.5 kN/m (786 plf) by 0.92 (see Footnote c to Table 3), which yields 12.5 kN/m (854 plf).

Table 4. Clemson Test Results.

Wall ID	Test Results (kN/m)		Uplift / Shear	Design Values [a] (kN/m)		Load Factor [b]	
	Uplift	Shear		Uplift	Shear	Uplift	Shear
Uni-axial Tests							
1a	27.8	NA	NA	12.6	NA	2.20	NA
1b	27.5					2.18	
2	NA	11.0	NA	NA	4.9	NA	2.24
Bi-axial Tests							
3a	19.7	8.7	2.3	9.5	4.9	2.08	1.78
3b	20.6	9.4	2.2			2.18	1.93
4a	15.7	13.9	1.1	7.9	7.1	1.99	1.94
4b	16.6	14.4	1.2			2.11	2.02
Average (Walls 4a and 4b)						2.05	1.98

[a] For wind load duration.

[b] Targeted load factor is 2.0.

Table 5. APA Test Results.

Wall [a] ID	Test Results (kN/m) Uplift	Test Results (kN/m) Shear	Uplift / Shear	Design Values [b] (kN/m) Uplift	Design Values [b] (kN/m) Shear	Load Factor [c] Uplift	Load Factor [c] Shear
Uni-axial Tests							
A1	46.4	NA	NA	16.6	NA	2.78	NA
A2	50.1					3.01	
Average (Walls A1 and A2)						2.90	
A3	NA	19.1	NA	NA	6.9	NA	2.74
Bi-axial Tests							
A4	28.3	16.9	1.68	12.5	6.9	2.27	2.43
A5	25.9	15.5	1.67			2.08	2.23
A6	26.8	16.4	1.64			2.15	2.35
Average (Walls A4, A5, and A6)						2.17	2.34

[a] The anchor/holddown bolts were installed finger-tight with an additional 1/8 turn except for Wall A6, which was wrench-tight.

[b] For wind load duration.

[c] Targeted load factor is 2.0.

3.1 Failure Modes

Among all uni-axial tests, Walls 1a, 1b, A1, and A2 (uplift only) failed due to nail withdrawal from the top plates and panel tear-out. Walls 2 and A3 (shear only) failed by a combination of nail withdrawal and nail-head pull through. Among all bi-axial tests, Wall 3a failed as a result of cross-bending failure on the bottom plate of the wall due to the use of thin 3.2 mm (0.125 in.) plate washers. When the thicker 5.8 mm (0.229 in.) plate washers were used, the plate washers did not bend and there was no cross-grain bending failure on the wall bottom plate. Figures 3 through 5 show the typical failure modes.

Figure 3. Panel tear-out and withdrawal of top plates (Wall 3b)

Figure 4. Typical failure mode from combined shear and uplift tests (Wall A5)

Figure 5. Typical failure mode from uplift only tests (Wall A2)

3.2 Load and Real Time Plots

Typical load and real time plots are shown in Figures 6 through 8.

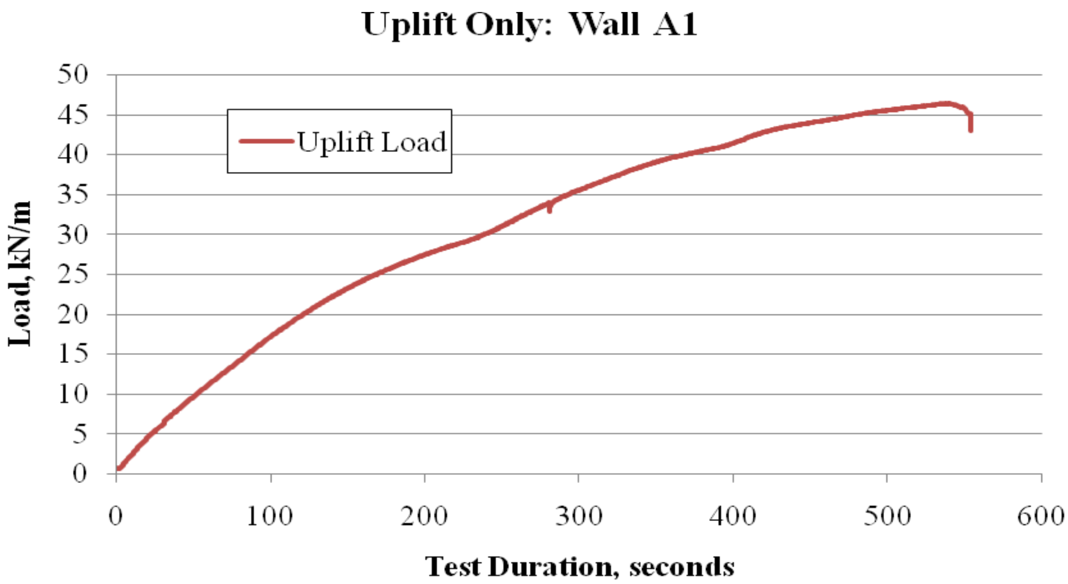

Figure 6. Test results from Wall A1 (uplift only)

3.3 Discussion

Results obtained from these studies confirm that the load factors for combined shear and uplift of walls constructed with 11 mm (7/16 in.) and 12 mm (15/32 in.) OSB panels are approximately 2.0, which is deemed adequate for wind design. This validates the uplift values calculated in accordance with the engineering mechanics analysis (i.e., NDS-05) and the shear values published in SDPWS provided that 5.8 x 76 x 76 mm (0.229 x 3 x 3 in.) plate washers are installed with anchor bolts spaced at 406 mm (16 in.) or less on center so that the cross-grain bending of the bottom wall plate can be avoided.

Test results obtained from these studies also support the conclusion that the holdowns do not affect the uplift resistance of walls constructed with wood structural panels (see results from Walls 1a with holdowns and 1b without holdowns). While this is not unexpected since holdowns are designed primarily to resist the overturning moment due to lateral loads, the test results confirm this general expectation.

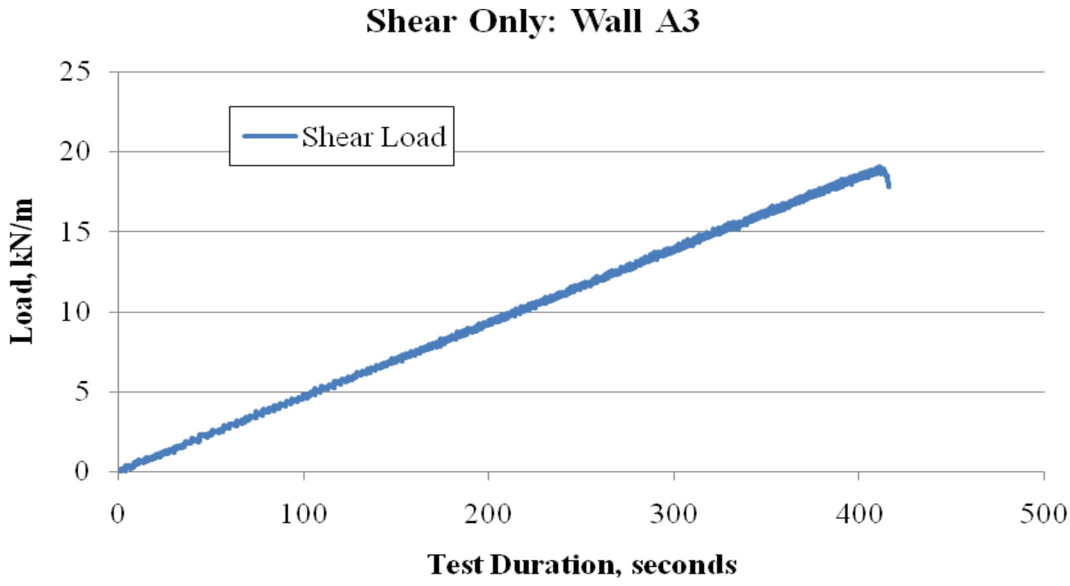

Figure 7. Test results from Wall A3 (shear only)

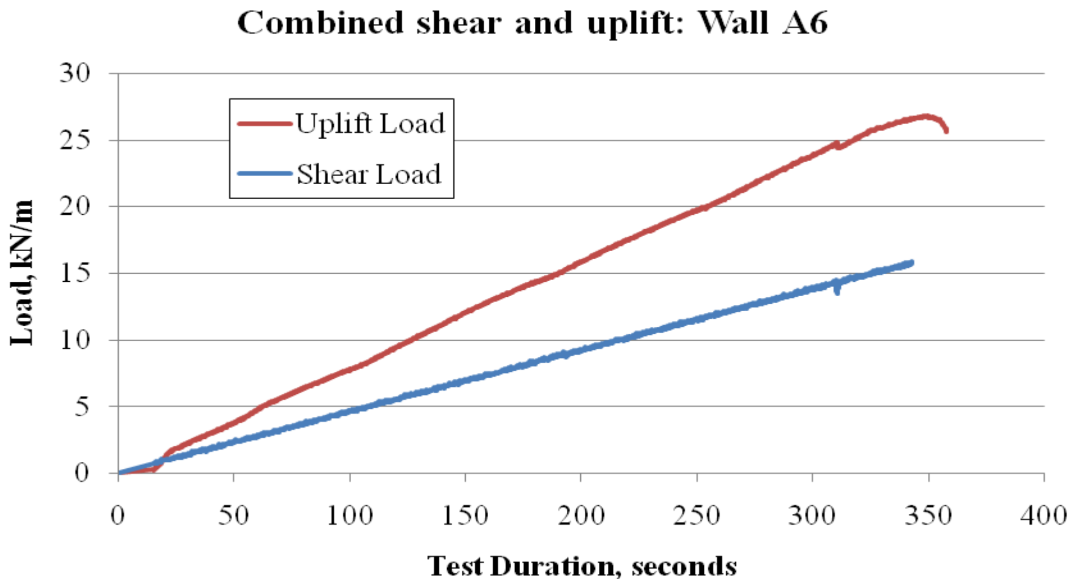

Figure 8. Test results from Wall A6 (combined shear and uplift)

4. Conclusions and Recommendations

Results obtained from these studies confirm the adequacy of using an engineering mechanics analysis to evaluate the resistance of shearwalls when subjected to combined shear and wind uplift provided that that 5.8 x 76 x 76 mm (0.229 x 3 x 3 in.) plate washers are installed with anchor bolts spaced at 406 mm (16 in.) or less on center so that the cross-grain bending of the bottom wall plate can be avoided. In the future, the anchor bolt spacing may be further optimized and the design values provided in Table 3 of this paper expanded to include other shearwall configurations.

5. References

1. International Code Council. 2006. *International Building Code*. Country Club Hills, IL.
2. International Code Council. 2006. *International Residential Code*. Country Club Hills, IL.
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4. National Institute of Standards and Technology. 2004. Voluntary Product Standard PS2-04, *Performance Standard for Wood-Based Structural-Use Panels.* Gaithersburg, MD.
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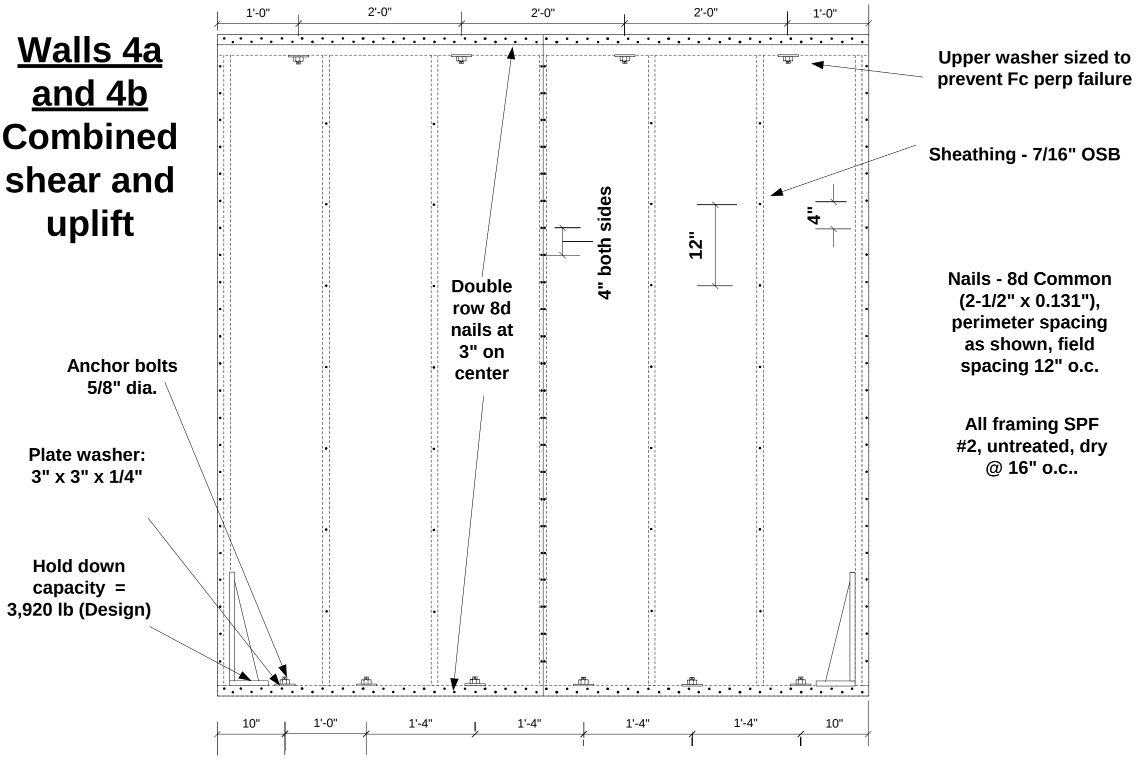
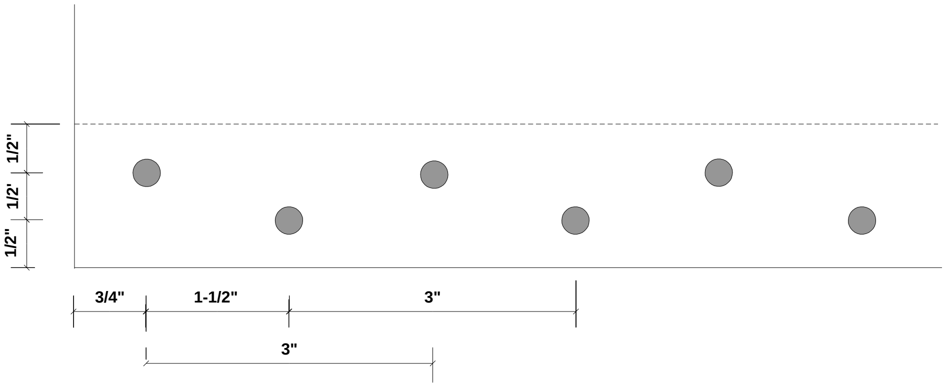
10. American Forest & Paper Association. 2005. *National Design Specification for Wood Construction*. Washington, D.C.
11. NAHB Research Center. 2005. Full-Scale Tensile and Shear Wall Performance Testing of Light-Frame Wall Assemblies Sheathed with Windstorm OSB Panels. Upper Marlboro, MD.

Appendix A. Example details for tested assemblies





Nailing pattern on the bottom plate (1 in. = 25.4 mm)