WCTE
WORLD CONFERENCE ON TIMBER ENGINEERING
2010

USING WOOD STRUCTURAL PANELS FOR SHEAR AND WIND UPLIFT APPLICATIONS

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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*, and provided the shear resistance of structural panels in 1999. When wood structural panels are used in combined shear and wind uplift, SSTD 10-99 also tabulated the wind uplift resistance of structural panels with a minimum thickness of 12 mm (15/32 inch) when used in combination with the shear resistance table. In the last few years, there have been several research projects led by APA – The Engineered Wood Association in the advancement of knowledge in this application.

APA constructed new combined shear and wind uplift test equipment that is capable of biaxial loading in both lateral and vertical directions with independent but synchronized loading systems. The vertical load can be applied as either an uplift force or a downward gravity load. Research results using this new equipment are used to enhance the understanding of the design on the biaxial combined shear and wind uplift. As a result, the 2008 *ANSI/AF&PA Special Design Provisions for Wind and Seismic* (SDPWS) includes the combined shear and wind uplift provisions based on the new information obtained from the APA research.

A substantial restriction exists in the 2008 SDPWS by requiring anchor bolts be installed at a maximum of 406 mm (16 inches) on center. This requirement is conservative in many cases, but was adopted because of the lack of supporting data to justify otherwise. Further investigation in optimizing the anchor bolt spacing has been conducted by APA after the publication of the 2008 SDPWS, which allows for varying anchor bolt spacing based on the magnitude of the lateral shear and uplift forces. This paper provides full-scale combined shear and uplift test data to support the development of the optimized anchor bolt spacing for the combined shear and uplift applications using wood structural panels.

KEYWORDS: Wood structural panels, Combined shear and uplift, Anchor bolt spacing

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 have been 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 designed for lateral forces induced by 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 10-99, *Standard for Hurricane Resistant Residential Construction* [6], which provided not only the shear resistance, but 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

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the nails installed in the shearwall assembly are used primarily to resist the lateral shear forces. If there are extra nails that exceed 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 typically 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 plates 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 large plate washers that are thick and wide enough to hold the bottom plates in place without inducing splitting.

Due to the merger of three regional U.S. model building codes into the IBC in 2000, SBCCI was no longer in existence and the 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 the SSTD 10. In the meantime, the International Code Council (ICC) published the ICC 600, *Standards for Residential Construction in High Wind Regions* [8] in 2008 and the American Forest & Paper Association (AF&PA) also revised the ANSI/AF&PA *Special Design Provisions for Wind and Seismic* (SDPWS) [9] at the same year. All of the referenced standards mentioned above contain provisions for combined shear and wind uplift using wood structural panels. The SDPWS revisions included the re-calculation of the mechanics-based uplift resistance using the nail yield model specified in the 2005 *National Design Specification for Wood Construction* (NDS) [10] and supported by the research results provided by APA [11, 12]. Tables 1 and 2 show the nominal capacities of wood structural panel shearwalls for the combined shear and uplift, and uplift only, respectively, in accordance with the 2008 SDPWS.

Table 1. *Nominal Uplift Capacity of Wood Structural Panels for Combined Shear and Wind Uplift*[a]

	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
	Nominal Uplift Capacity (kN/m)[b,c]											
Nails-Single Row[d]	0.0	2.5	4.9	0.0	3.2	6.3	NP	0.0	3.2	0.0	3.8	7.6
Nails-Double Row[e]	4.9	9.8	14.7	6.3	12.6	18.9	3.2	9.5	15.8	7.6	15.3	22.9

1 mm = 0.0394 in., 1 kN/m = 68.5 lbf/ft

(a) Minimum 11-mm (7/16-inch) OSB. The framing species shall have a published specific gravity of 0.42 (spruce-pine-fir) or greater. Anchor bolts shall be installed at 406 mm (16 in.) on center.

(b) For framing with a specific gravity of 0.49 or greater, multiply the listed uplift values by 1.08.

(c) 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 or plywood with a species of plies having a specific gravity of 0.49 or greater. For plywood with other species, multiple the tabulated uplift values by 0.90.

(d) 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.

(e) 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.

Table 2. *Nominal Uplift Capacity of Wood Structural Panels for Wind Uplift Only*[a]

	6d @ 152 & 305 mm			8d @ 152 & 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
	Nominal Uplift Capacity (kN/m)[b,c]								
Nails-Single Row[d]	4.7	7.0	9.3	6.1	9.1	12.1	7.3	10.9	14.6
Nails-Double Row[e]	9.3	14.0	18.7	12.1	18.2	24.3	14.6	21.9	29.2

1 mm = 0.0394 in., 1 kN/m = 68.5 lbf/ft

(a) Minimum 9.5-mm (3/8-in.) OSB. The framing species shall have a published specific gravity of 0.42 (spruce-pine-fir) or greater. Anchor bolts shall be installed at 406 mm (16 in.) on center.

(b) For framing with a specific gravity of 0.49 or greater, multiply the listed uplift values by 1.08.

(c) The tabulated values are applicable to 9.5 mm (3/8 in.) minimum OSB panels or plywood with species of plies having a specific gravity of 0.49 or greater. For plywood with other species, multiple the tabulated uplift values by 0.90.

(d) 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.

(e) 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.

A substantial restriction exists in the 2008 SDPWS by requiring the anchor bolts be installed at a maximum of 406 mm (16 inches) on center. This requirement is conservative in many cases, but was adopted because of the lack of supporting data to justify otherwise. Further investigation in optimizing the anchor bolt spacing has been conducted by APA after the publication of the 2008 SDPWS, which allows for varying anchor bolt spacing based on the magnitude of the lateral shear and uplift forces. This paper provides full-scale combined shear and uplift test data to support the development of the optimized anchor bolt spacing for the combined shear and uplift applications using wood structural panels.

2 DEVELOPMENT OF ANCHOR BOLT SPACING

A number of assumptions were made in the development of the anchor-bolt spacing matrix, as illustrated in Table 3 and discussed below.

***Table 3.** Development of anchor bolt spacing (mm) based on lumber framing specific gravity (SG)*

Nail (Common)	Nominal Unit Shear (kN/m)		Nominal Unit Uplift (kN/m)										
	SG 0.50		0	3.2	6.3	9.5	12.6	15.8	18.9	21.3	25.2	28.4	31.5
		SG 0.42	0	2.9	5.8	8.8	11.7	14.6	17.5	19.7	23.4	26.3	29.2
8d @ 102 mm (11-mm panel)	0	0									406		
	5.8	5.4									406		
	9.8	9.0									406		
	14.3	13.2											
10d @ 152 mm (12-mm panel)	0	0									406	406	406
	5.8	5.4									406		
	12.7	11.7								406			

Linear interpolation – Item (e) below

Shears based on the SDPWS shear table – Item (a) above

Shear-only values based on the NDS Table 11E – Item (c) below

Range based on Table 1 – Item (b) below

406 mm (16 in.) oc based on previous testing – Item (d) below

1 mm = 0.0394 in., 1 kN/m = 68.5 lbf/ft

a) The "Nominal Unit Shear" values were selected from the shearwall design values of the SDPWS to cover a range of values from the "Nail Spacing Required for Shearwall Design" columns in Table 1. An intermediate shear value of 5.8 kN/m (400 plf) with the SG = 0.50 was added to facilitate utilization for low-shear applications.
b) The "Nominal Unit Uplift" values were selected from 0 to 31.5 kN/m (2,160 plf) with SG = 0.50, or 29.2 kN/m (2,000 plf) with SG = 0.42 based on a range of values for uplift-only in Table 2 (note that the tabulated values in Table 2 are based on SG = 0.42). Intermediate increments were chosen for tabulation purposes.
c) The shear-only values in the table ("Nominal Unit Uplift" value of 0) were calculated based on the 2005 NDS for 13-mm (½-inch) anchor bolts and single shear (two-member) connection. The table provides for the anchor bolt to be fixed (embedded in concrete), and values for a compressive load parallel to the grain ($Z_{//}$) for SG = 0.50 were used ($Z_{//}$ = 2.9 kN/bolt or 650 lbf/bolt). A duration of load of 1.6 was applied to the allowable load, yielding:

$$2.9 \text{ kN/bolt} \times 1.6 = 4.6 \text{ kN/bolt}$$

Note that the anchor bolt spacings for shear-only were truncated at 1219 mm (48 inches) on center as this is the most conservative prescriptive anchor-bolt spacing required in the 2009 IBC and IRC.
d) Testing conducted previously by APA and others at the upper bound levels of high shear and high uplift illustrated that anchor bolt spacing at 406 mm (16 inches) on center and the use of 5.8- x 76- x 76-mm (0.229- x 3- x 3-inch) plate washers between nut and bottom plate were required to prevent a tension-perpendicular-to-grain (cross-grain bending) failure of the bottom plate. These prior results were confirmed by this latest series of tests. As the maximum shear and uplift testing conducted by APA for the other upper-bound shear and uplift cells of the matrix was successfully completed with an anchor bolt spacing of 406 mm (16 inches), this value was used for all other upper-bound values in Table 3.
e) With values fixed on the left hand side of Table 3 by Item c above and on the right hand side by Item d, the intermediate values were interpolated based on the "Nominal Unit Uplift" values. The "missing" upper-bound value in Table 3 for 8d nails at 21.3 kN/m (1,458 plf) uplift and 14.3 kN/m (980 plf) shear, both SG = 0.50, was assumed to be 406 mm (16 inches). This was later confirmed by Test B5 that will be discussed later.
f) The above model yields the anchor bolt spacings shown in Table 4 by linear interpolation.

Table 4. Proposed anchor bolt spacing (mm) based on model[(a)]

Nail (Common)	Nominal Unit Shear (kN/m)		Nominal Unit Uplift (kN/m)										
	SG 0.50		0	3.2	6.3	9.5	12.6	15.8	18.9	21.3	25.2	28.4	31.5
		SG 0.42	0	2.9	5.8	8.8	11.7	14.6	17.5	19.7	23.4	26.3	29.2
8d @ 102 mm (11-mm panel)	0	0	1219	1118	1016	914	813	711	610	533	406		
	5.8	5.4	1219	1118	1016	914	813	711	610	533	406		
	9.8	9.0	940	864	813	737	686	610	533	483	406		
	14.3	13.2	635	610	559	533	508	457	432	**406**[(b)]			
10d @ 152 mm (12-mm panel)	0	0	1219	1118	1016	914	813	711	610	533	406	406	406
	5.8	5.4	1219	1118	1016	914	813	711	610	522	406		
	12.7	11.7	711	660	610	584	533	483	432	406			

1 mm = 0.0394 in., 1 kN/m = 68.5 lbf/ft

(a) Shaded cells are outside the range of the SDPWS. Boxed cells were chosen to be tested for model verification. See Tables 5 and 6 for specific details.

(b) This cell is outside the range of the SDPWS, but was tested for model verification.

3 MATERIAL AND METHODS

3.1 TEST FRAME

Testing was conducted on a test frame designed for combined shear and uplift testing at the APA Research Center in Tacoma, WA, as shown in Figure 1. This test frame consists of a free-standing rigid rectangular steel frame designed to act as a reaction frame for both horizontal and vertical forces. For this study, the horizontal hydraulic cylinders were set up to apply a positive pressure to the assembly (place the wall in shear) and the vertical hydraulic cylinders were configured to pull upwards (place uplift on the wall). Lateral restraints were provided by steel box sections with a low friction contact surface placed near the top of the assembly. Lateral restraints at the base were provided by the assembly attachment to the rigid base plate. The test frame was designed to permit a number of different wall configurations from 1219 mm x 2438 mm (4 feet x 8 feet) to 3048 mm x 3658 mm (10 feet x 12 feet). For this study, an assembly size of 2438 mm x 2438 mm (8 feet x 8 feet) was used.

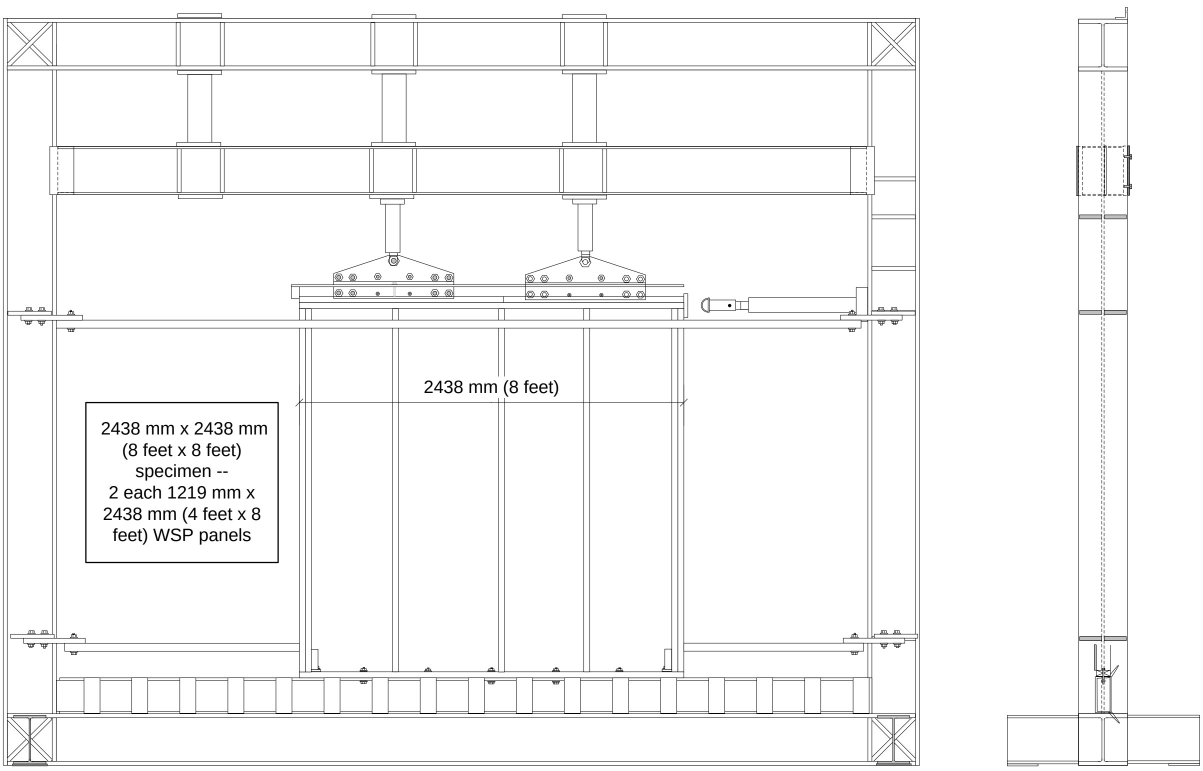

***Figure 1.** Combined shear and uplift test frame*

The test assemblies were attached to the base of the test frame with anchor bolts in predrilled holes. For unusual anchor bolt spacing, machine clamps were utilized to attach the test assembly to the base of the test frame. When used, these clamps secured the wall through short bolt sections consisting of a bolt head with a 38-mm (1-1/2-inch) shank. The clamp was placed over the head of the bolt section and attached to the flange of the rest frame bed. This provided virtually identical restraint conditions as provided by flat plate washers and anchor bolts.

The vertical and horizontal hydraulic cylinders were set up to provide independent control along each axis but were linked by a computer to synchronize them to meet their independent targeted test loads within the same time period. Load data were recorded electronically as a function of time for motion in both directions.

3.2 TEST ASSEMBLIES

Combined shear and uplift test assemblies were constructed in accordance with Figure 2 using materials listed in Table 5. Hold-downs sized in accordance with Table 5 were provided at each end of the specimen and attached to the inside of the double studs with 6.4-mm (1/4-inch) Simpson SDS screws. The targeted assembly capacities are shown in Table 6. Table 7 illustrates the position of the test assembly in the final anchor bolt spacing matrix.

Table 5. *Materials used for test assemblies*

Test Series	Framing	Sheathing[a] (mm)	Nail (Common)	Nail Pattern on Top and Bottom Plates	Hold Down		Anchor Bolts[b]	
					Type	# SDS Screws	Dia. (mm)	Tested Spacing (mm)
A0	All framing DF #2 or better, 610 mm (24 in.) oc with a single center stud (SG = 0.50)	11	8d	2 rows @ 152 mm	PHD6	7	12.7	813
A2		11	8d	2 rows @ 102 mm	PHD6	9	12.7	610
A3		11	8d	1 row @ 102 mm & 1 row @ 152 mm	PHD6	12	12.7	813
B1		11	8d	1 row @ 152 mm	–	–	12.7	1219
B4		11	8d	2 rows @ 76 mm	PHD6	9	12.7	406
B5		11	8d	2 rows @ 76 mm	PHD6	16	12.7	406
B9		12	10d	1 row @ 102 mm	–	–	12.7	813
B10		12	10d	2 rows @ 152 mm	PHD6	11	12.7	610
C1[c]		11	8d	1 row @ 76 mm & 1 row @ 102 mm	–	–	12.7	406
C3[c]		11	8d	2 rows @ 102 mm			12.7	610
C4[c]		12	10d	2 rows @ 102 mm			12.7	406
C5[c]		12	10d	2 rows @ 76 mm			12.7	406
C6[c]		12	10d	1 row @ 76 mm & 1 row @ 102 mm	PHD5	11	12.7	406
C7[c]		12	10d	2 rows @ 76 mm	–	–	12.7	406

1 mm = 0.0394 in.

(a) APA Rated OSB Sheathing meeting the DOC PS2.

(b) 5.8- x 76- x 76-mm (0.229- x 3- x 3-inch) plate washers were used between nut and bottom plate.

(c) Multiple tests in this series.

Table 6. *Targeted assembly capacities (framing SG = 0.50)*

Test Series	Nominal Shear		Nominal Uplift	
	Target Unit Shear (kN/m)	Target Total Shear (kN)	Target Unit Uplift (kN/m)	Target Total Uplift (kN)
A0	5.8	14.2	9.5	23.1
A2	9.8	23.8	15.8	38.4
A3	14.3	34.9	3.2	7.7
B1	–	–	3.2	7.7
B4	9.8	23.8	25.2	61.5
B5	14.3	34.9	21.3	51.9
B9	–	–	12.6	30.7
B10	12.7	31.0	6.3	15.4
C1[a]	–	–	25.2	61.5
C3[a]			18.9	46.1
C4[a]			25.2	61.5
C5[a]			28.4	69.2
C6[a]	12.7	31.0	21.3	51.9
C7	–	–	31.5	76.9

1 kN/m = 68.5 lbf/ft, 1 kN = 224.8 lbf

(a) Multiple tests in this series.

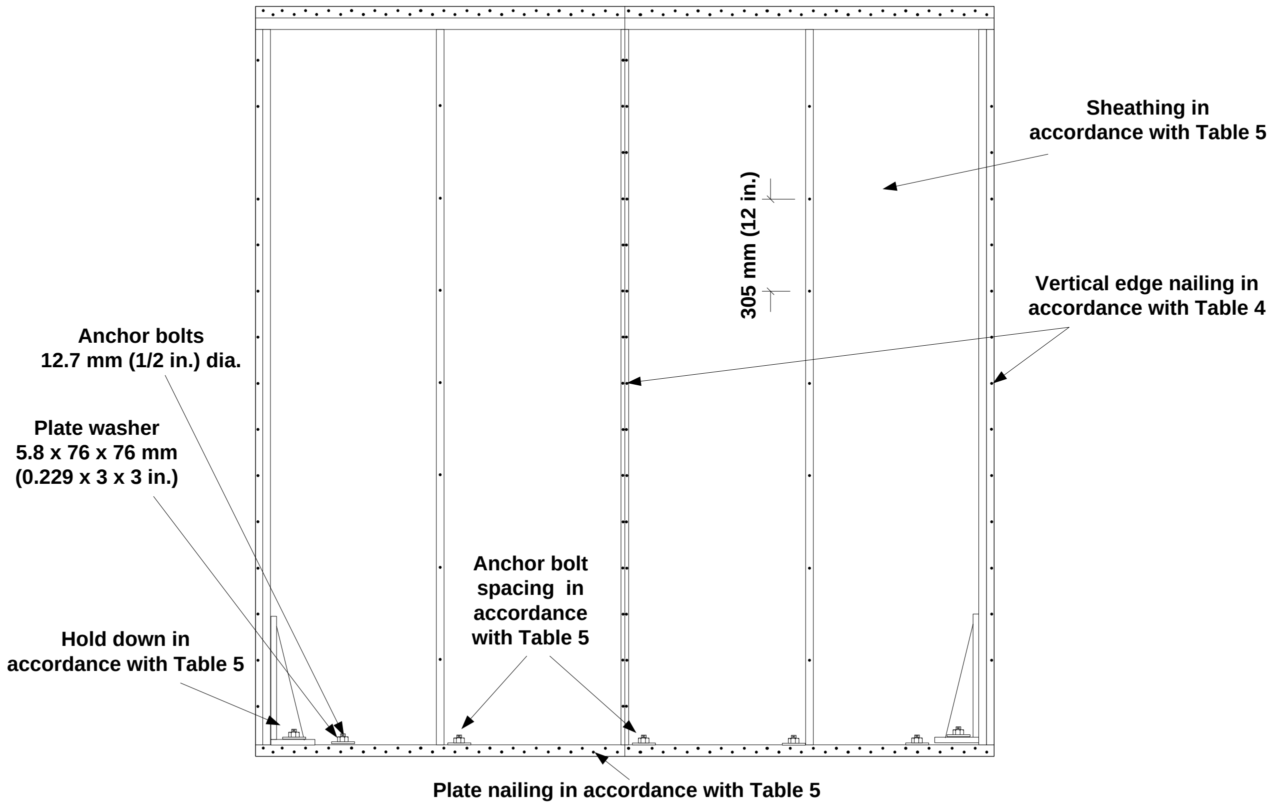

Figure 2. *Configuration for shear and uplift assemblies*

Table 7. *Test assembly location in the final anchor bolt spacing matrix*[(a)]

Nail (Common)	Nominal Unit Shear (kN/m)		Nominal Unit Uplift (kN/m)										
	SG 0.50		0	3.2	6.3	9.5	12.6	15.8	18.9	21.3	25.2	28.4	31.5
		SG 0.42	0	2.9	5.8	8.8	11.7	14.6	17.5	19.7	23.4	26.3	29.2
8d @ 102 mm (11-mm panel)	0	0	(c)	B1					C3		C1		
	5.8	5.4	(c)			A0							
	9.8	9.0	(c)					A2			B4		
	14.3	13.2	(c)	A3						**B5**[(b)]			
10d @ 152 mm (12-mm panel)	0	0	(c)				B9				C4	C5	C7
	5.8	5.4	(c)										
	12.7	11.7	(c)		B10					C6			

1 mm = 0.0394 in., 1 kN/m = 68.5 lbf/ft

(a) Shaded cells are outside the range of the SDPWS. Boxed cells were chosen to be tested for model verification.

(b) This cell is outside the range of the SDPWS, but was tested for model verification.

(c) This cell represents the shear-only value.

3.3 INSTRUMENTATION

Simultaneous shear and uplift loads were measured and recorded continuously by commercial data acquisition software in both the vertical and horizontal directions for the duration of each test.

3.4 INSTALLATION OF TEST ASSEMBLIES

Test assemblies were loaded into the test apparatus and anchored to the base in accordance with the details in Table 5. Anchor bolts of 12.7 mm (1/2 inch) in diameter and 5.8- x 76- x 76-mm (0.229- x 3- x 3-inch) plate washers were used to resist the uplift component along with hold downs to resist overturning. The rectangular plate washers were approximately aligned with the flat sides parallel to the sheathing. Hold downs were bolted to the base of the test apparatus in predrilled holes when the holes were present. When predrilled holes were not available to accommodate the anchor bolt spacing required, machine clamps were provides at the required locations, as discussed before. Hold downs were attached to the double end studs in accordance with the hold down manufacturer's recommendations with the exception that only sufficient fasteners (6.3- x 76-mm or 1/4- x 3-inch SDS screws) were used to develop the required overturning capacity resulting from the shear forces on the assembly.

At the top of the test assembly, a 12.7- x 178-mm (1/2- x 7-inch) metal plate was attached. This plate was attached with metal angles located at 406 mm (16 inches) on center. These angles were predrilled to provide an attachment pattern and schedule. In lieu of the nails required to attach the framing anchor, screws were used (#9 x 51-mm or 2-inch square drive flat-head screws) to facilitate disassembly. The 12.7- x 178-mm (1/2 x 7-inch) plate was engaged by the vertical loading heads when the uplift force was applied thus putting tension on the test assembly via the metal angles and framing anchors in a manner similar to a walls reaction to high wind loads within a structure.

At the edge of the assembly adjacent to the horizontal hydraulic cylinder, a metal bearing plate was applied at the center over the double top plates. The hydraulic cylinder engaged the metal plate vial a series of steel rollers. These were used to permit the assembly to move laterally and rotate during loading without introducing any additional constraints other than the vertical and horizontal loads applied into the wall system.

3.5 TEST METHODS

The test assemblies were tested in accordance with Section 14 of ASTM E 72 [13] and Figure 1. The assemblies were loaded to the targeted loads, as shown in Table 6 in two minutes.

4 RESULTS AND DISCUSSION

Test results of this study are shown in Table 8. The targeted combined shear and uplift load factor is 2.0. Note that the target uplift and shear values shown in Table 8 are nominal values. When calculating load factors, the nominal value is divided by 2.0 to yield the allowable design value. As such, the load factor is calculated in accordance with Eq. 1.

$$Load\ Factor = \frac{Test\ Result}{\left(\frac{Nominal\ Targeted\ Value}{2.0}\right)} \qquad (1)$$

The average load factor shown in Table 8 is calculated based on the average of the uplift and shear load factor.

Table 8. *Test results (framing SG = 0.50)*

Test ID	Shear (kN/m)		Uplift (kN/m)		Load Factor(a)		Average Load Factor(b)
	Nominal Target	Test Results	Nominal Target	Test Results	Shear	Uplift	
A0	5.8	6.5	9.5	20.7	2.2	4.4	3.3
A2	9.8	11.7	15.8	17.8	2.5	2.3	2.4
A3	14.3	18.4	3.2	4.4	2.6	2.8	2.7
B1	–	–	3.2	10.5	–	6.7	6.7
B4	9.8	10.3	25.2	24.9	2.1	2.0	2.1
B5	14.3	20.1	21.3	23.3	2.8	2.2	2.5
B9	–	–	12.6	19.0	–	3.0	3.0
B10	12.7	16.4	6.3	8.1	2.6	2.6	2.6
C1A	–	–	25.2	25.5	–	2.0	2.0
C1B				25.6		2.0	
C3A			18.9	25.0		2.7	2.8
C3B				26.4		2.8	
C4A			25.2	25.8		2.0	2.3
C4B				33.2		2.6	
C5A			28.4	30.7		2.3	2.3
C5B				35.6		2.6	
C5C				30.5		2.2	
C5D				28.9		2.1	
C5E				29.1		2.2	
C6A	12.7	12.1	21.3	23.1	1.9	2.2	2.0
C6B		12.2		22.7	1.9	2.2	
C6C		11.9		21.8	1.9	2.1	
C6D		12.6		22.8	2.0	2.2	
C6E		11.0		20.5	1.8	2.0	
C7A	–	–	31.5	46.4	–	2.9	3.0
C7B				50.1		3.2	

1 kN/m = 68.5 lbf/ft

(a) Load Factors were calculated in accordance with Eq. 1.

(b) Average Load Factor is based on the average of the uplift and shear load factors.

As shown in Table 8, the load factors for those 26 assembly testes in this study are typically in the range of 2 to 3. One exception is Wall B1, which is uniaxial (uplift-only) at a very low targeted uplift force. In some critical load cases (high uplift-only or combined shear and uplift), such as Walls C5 and C6 series, additional replicates were tested to increase the data confidence.

It should be noted that all tests reported in Table 8 used 12.7-mm (1/2-in.) diameter anchor bolts, which are different from the current requirements of 15.9-mm (5/8-in.) anchor bolts specified in the SDPWS and the ICC-600. Test results obtained from this study showed that the 12.7-mm (1/2-in.) diameter anchor bolts are adequate for use in the combined shear and uplift applications when the design loads are within the range permitted in the current U.S. national design standards.

4.1 FAILURE MODES

The typical failure modes for uniaxial tests, such as Walls B1, C1A through C5E, C7A and C7B (uplift only), were the nail withdrawal from the top and bottom plates, and panel edge tear-out, as shown in Figure 3. For biaxial tests (combined shear and uplift), the failure modes were more complicated. At the high combined loading, such as Walls C6A through C6E, it was usually a combination of nail withdrawal from the top and bottom plates, panel edge tear-out, and the bottom plate failure, as shown in Figure 4. The 5.8- x 76- x 76-mm (0.229- x 3- x 3-inch) plate washers performed adequately to avoid cross-grain bending failure on the bottom plate in most cases. It is important, however, to pay attention to the anchor bolt spacing as the cross-grain bending is a possibility if the anchor bolts are not properly spaced.

Figure 3. *Nail withdrawal from bottom and top plates, and panel edge tear-out from uniaxial (uplift-only) tests*

Figure 4. *A combination of nail withdrawal, panel edge tear-out, and bottom plate failure from biaxial (combined shear and uplift) tests*

5 CONCLUSION

As shown by the results in Table 8, load factors of 2.0 or greater were achieved by the assemblies selected to verify the model used to develop Table 4. As the anchor bolt spacings listed in Table 4 may be difficult to construct in the field, Tables 9 and 10 were developed. Table 9 provides anchor bolt spacings rounded down from Table 4 to 152-mm (6-inch) increments on center. The anchor bolt spacing of 406 mm (16 inches) on center were unchanged in Table 9 as this spacing is a commonly used construction spacing interval in North America, is widely published, and currently exclusively recommended for combined shear and uplift anchor bolt spacing. For practical use, Table 10 further rounds the anchor both spacing from Table 4 down to traditional spacing intervals of 406, 488, 610, 813, 914, 1067, and 1219 mm (16, 19.2, 24, 32, 36, 42, and 48 inches) used in the conventional construction in North America.

***Table 9.** Anchor bolt spacing (mm) rounded down to spacing with 152-mm (6-inch) increments*

Nail (Common)	Nominal Unit Shear (kN/m)		Nominal Unit Uplift (kN/m)										
	SG 0.50		0	3.2	6.3	9.5	12.6	15.8	18.9	21.3	25.2	28.4	31.5
		SG 0.42	0	2.9	5.8	8.8	11.7	14.6	17.5	19.7	23.4	26.3	29.2
8d @ 102 mm (11-mm panel)	0	0	1219	1067	1016	914	762	610	610	457	406		
	5.8	5.4	1219	1067	1016	914	762	610	610	457	406		
	9.8	9.0	914	762	762	610	610	610	457	457	406		
	14.3	13.2	610	610	457	457	457	457	406				
10d @ 152 mm (12-mm panel)	0	0	1219	1067	914	914	762	610	610	508	406	406	406
	5.8	5.4	1219	1067	914	914	762	610	610	508	406		
	12.7	11.7	610	610	610	457	457	457	457	406			

1 mm = 0.0394 in., 1 kN/m = 68.5 lbf/ft

***Table 10.** Anchor bolt spacing (mm) rounded down to common construction spacings*

Nail (Common)	Nominal Unit Shear (kN/m)		Nominal Unit Uplift (kN/m)										
	SG 0.50		0	3.2	6.3	9.5	12.6	15.8	18.9	21.3	25.2	28.4	31.5
		SG 0.42	0	2.9	5.8	8.8	11.7	14.6	17.5	19.7	23.4	26.3	29.2
8d @ 102 mm (11-mm panel)	0	0	1219	1067	914	914	813	610	610	488	406		
	5.8	5.4	1219	1067	914	914	813	610	610	488	406		
	9.8	9.0	914	813	610	610	610	610	488	488	406		
	14.3	13.2	610	610	488	488	488	406	406				
10d @ 152 mm (12-mm panel)	0	0	1219	1067	914	914	813	610	610	488	406	406	406
	5.8	5.4	1219	1067	914	914	813	610	610	488	406		
	12.7	11.7	610	610	610	488	488	488	406	406			

1 mm = 0.0394 in., 1 kN/m = 68.5 lbf/ft

Results presented in Table 10 have been incorporated into the APA System Report SR-101, *Design for Combined Shear and Uplift from Wind* [14], which may be used by design engineers on a voluntary basis before the provisions can be adopted into the U.S. national design standards, such as the SDPWS and the ICC-600. Since the installation details are critical to the combined shear and uplift applications, APA SR-101 also provides many practical details to ensure the wall assemblies are properly designed and constructed. It would be prudent to follow the APA SR-101 construction details closely when designing and constructing wood structural panel shearwalls for the comnbined shear and wind uplift applications.

While APA SR-101 still recommends the use of 15.9-mm (5/8-in.) anchor bolts as specified in the SDPWS and the ICC-600, test results obtained from this study showed that the 12.7-mm (1/2-in.) diameter anchor bolts are adequate for use in the combined shear and uplift applications when the design loads are within the range permitted in the current U.S. national design standards.

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