Effect of Blocking in Horizontally Sheathed Shear Walls

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Abstract

In certain applications such as exterior wall sheathing, wood-based panels are at times applied horizontally to the wall frame without blocking. Based on a need identified by the engineering community, full-scale tests on unblocked shear walls were performed to determine their lateral load carrying capacity. The results showed that typical failures occur along the unblocked horizontal joint where the nails either withdraw from the framing members or pull through the panel. Based on the test results, strength adjustment factors for unblocked shear walls were proposed.

Introduction

Current wood design codes provide design values for shear walls sheathed with wood-based panels oriented either vertically or horizontally with framing blocking. In other words, perimeters of wood-based panels are always nailed to lumber framing. However, it is quite common to use shear walls sheathed horizontally with wood-based panels without blocking (Fig. 1). Although there are design values for unblocked diaphragms, values for unblocked shear walls are not available in U.S. codes.

In this study, full-scale shear walls were tested under static and reversed cyclic displacement schedules. Based on the test results obtained from this study and the results made available by APA–The Engineered Wood Association (Tissell 1990), strength adjustment factors for unblocked shear walls were proposed and implemented in the Canadian design code for wood (Canadian Standard Association 2001).

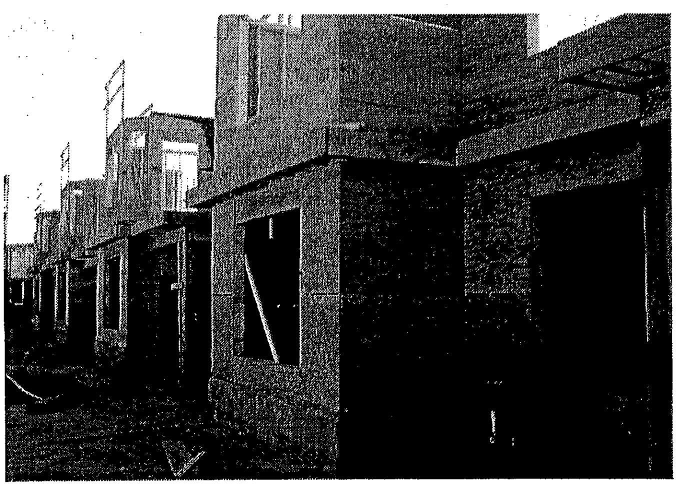

Figure 1.—Typical examples of use of unblocked shear walls in construction practice.

Test Program

Three types of unblocked shear walls, 2.44 m (8 ft.) in height and 4.88 m (16 ft.) in length, along with reference blocked shear walls, were tested under monotonic and reversed cyclic tests. The configurations of the wall types are shown in Figure 2. Wall type 1 has a horizontal gap in the middle of the wall; wall type 2 has two horizontal gaps with a 305 mm (12 in.) wide panel strip in the middle of the wall; and wall type 3 has staggered horizontal gaps at a distance of 610 mm (16 in.) from each other. For all unblocked shear walls, the horizontal gap between panels is 12.5 mm (1/2 in.).

All shear wall specimens were constructed using NLGA No. 2 and better grades of Spruce-Pine-Fir 38 by 89 mm (2 by 4 in.) lumber for the wall studs, and 1650f-1.5E MSR 38 by 89 mm (2 by 4 in.) lumber for the top and bottom plates. The top plate and end studs consisted of double members, while the bottom plate and interior studs consisted of single members. Canadian softwood plywood (CSP), 9.5 mm (3/8 in.) thick, was used for the sheathing panels, and was connected to framing members with type 8d smooth shank power nails. Detailed information about the shear wall test specimens is given in Table 1.

For each wall configuration, two specimens were tested: one under a static and one under a reversed cyclic displacement schedule. Although testing more replicates per wall configuration would be desirable, the use of two specimens per configuration was considered to give acceptable mean values for the lateral load resistances and displacements based on the low variability observed in previous tests.

Conditioning and testing of walls was performed at ambient laboratory conditions where average ovendry moisture content of both lumber and plywood were approxi-

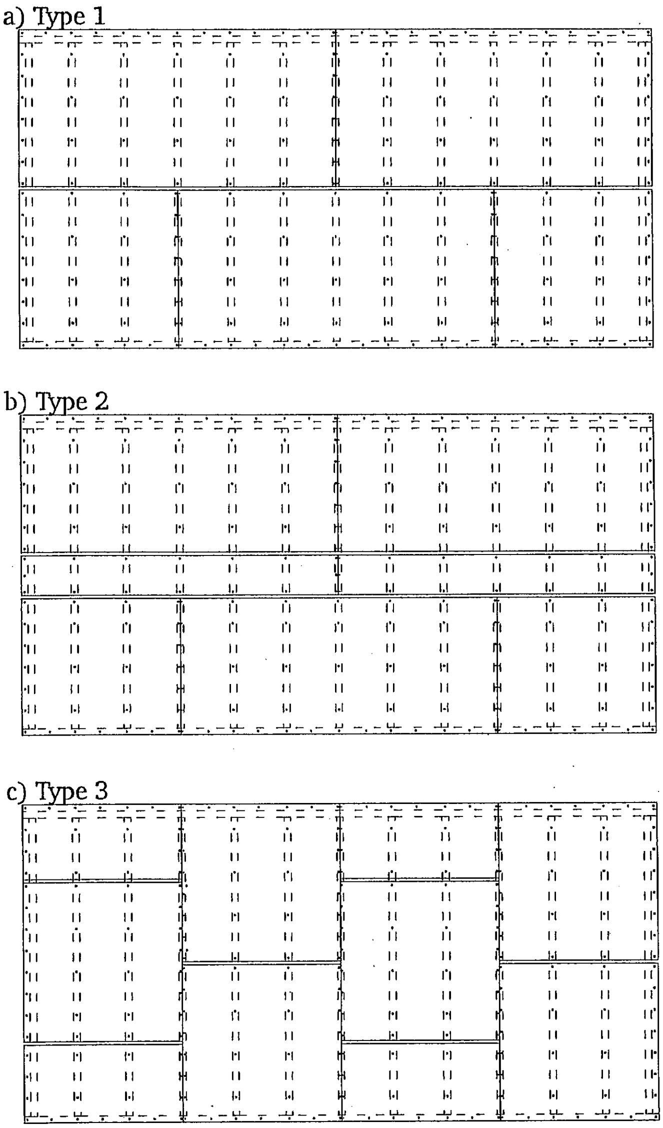

Figure 2.—Unblocked shear wall configurations considered in this study.

mately 9 percent. The average ovendry relative density of lumber was approximately 0.44.

Load Protocols

A ramp and two reversed cyclic displacement protocols were used for the tests. The two reversed cyclic protocols used are shown in Figure 3. FCC93 has a constant displacement frequency of 0.5 Hz, while ISO98 has a constant displacement rate of 20 mm/sec. The ISO98 protocol has been proposed for the working draft of the ISO Standard *Timber structures - Joints made with mechanical fasteners - Quasi-static reversed-cyclic test method* (ISO 1998).

Test Set-Up

A schematic drawing of the test set-up is shown in Figure 4. This configuration is similar to that described in the ASTM Standard E564 (1991). A detailed description of the test set-up can be found in Karacabeyli and Ceccotti (1996).

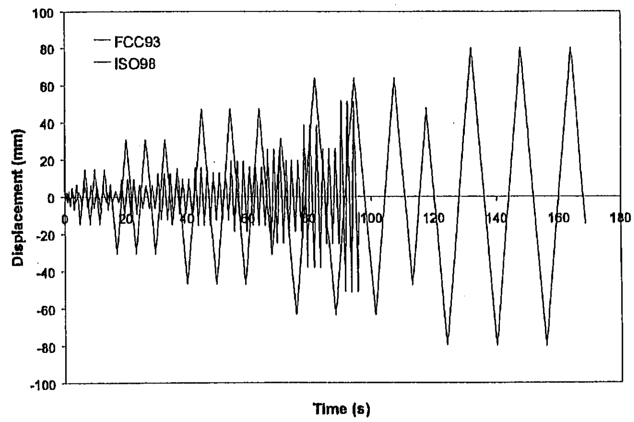

Figure 3.—Reversed cyclic protocols used in the tests.

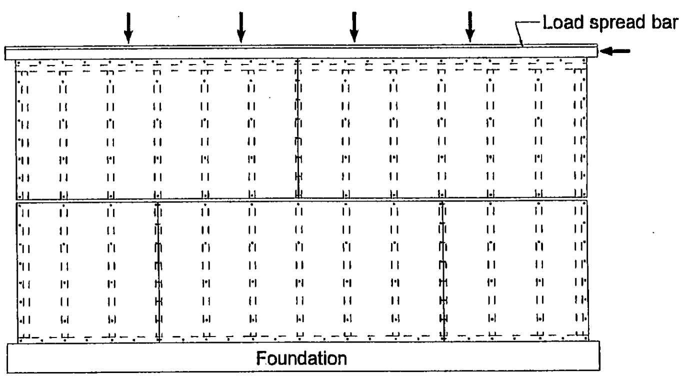

Figure 4.—Schematic test setup of unblocked shear walls under constant vertical and varying lateral loads.

Test Results

Table 2 summarizes maximum loads, ultimate displacements, and secant stiffness of blocked and unblocked shear walls. Ratios of maximum loads, ultimate displacements, and secant stiffness between unblocked and blocked shear walls are also included in Table 2.

Wall Configuration 1

Figure 5 shows load-displacement responses of blocked and unblocked shear walls sheathed horizontally with nail spacing of 150 mm (6 in.) at supported edges and 300 mm (12 in.) at intermediate studs under ramp and reversed cyclic tests. For framing members spaced 406 mm (16 in.) on center, capacities of unblocked shear walls had approximately 60 percent of the capacities of blocked shear walls for the same nail and stud spacing. Ultimate displacements and secant stiffnesses of unblocked shear walls were approximately 80 percent of those of blocked shear walls. Unlike blocked shear walls, where nail joints along the perimeter of the panels reached their capacities, for unblocked shear walls, only nail joints along the unblocked horizontal joint reached their capacities. Figure 6 shows the deformed shape of the un-

Table 1.—Test matrix of blocked and unblocked shear walls.

Specimen	Load protocol	Type	Vertical load (kN/m)	Panel	Stud spacing (mm)	Nail size	Nail spacing (mm) Supported edges	Intermediate studs
22-02	Ramp	Blocked	0	9.5 mm CSP	406	Power 8d	150	300
22-03	FCC93	Blocked	0	9.5 mm CSP	406	Power 8d	150	300
29-01	Ramp	1	0	9.5 mm CSP	406	Power 8d	150	300
29-02	FCC93	1	0	9.5 mm CSP	406	Power 8d	150	300
31-01	Ramp	Blocked	18.2	9.5 mm CSP	406	Power 8d	150	300
31-02	FCC93	Blocked	18.2	9.5 mm CSP	406	Power 8d	150	300
51-01	Ramp	1	18.2	9.5 mm CSP	406	Power 8d	150	300
51-02	FCC93	1	18.2	9.5 mm CSP	406	Power 8d	150	300
51-05	Ramp	1	18.2	9.5 mm CSP	305	Power 8d	150	150
51-06	ISO98	1	18.2	9.5 mm CSP	305	Power 8d	150	150
51-07	Ramp	1	18.2	9.5 mm CSP	406	Power 8d	100	100
51-08	ISO98	1	18.2	9.5 mm CSP	406	Power 8d	100	100
51-09	Ramp	1	18.2	9.5 mm CSP	610	Power 8d	100	100
51-10	ISO98	1	18.2	9.5 mm CSP	610	Power 8d	100	100
51-21	Ramp	2	18.2	9.5 mm CSP	406	Power 8d	150	150
51-22	ISO98	2	18.2	9.5 mm CSP	406	Power 8d	150	150
51-23	Ramp	3	18.2	9.5 mm CSP	406	Power 8d	150	150
51-24	ISO98	3	18.2	9.5 mm CSP	406	Power 8d	150	150

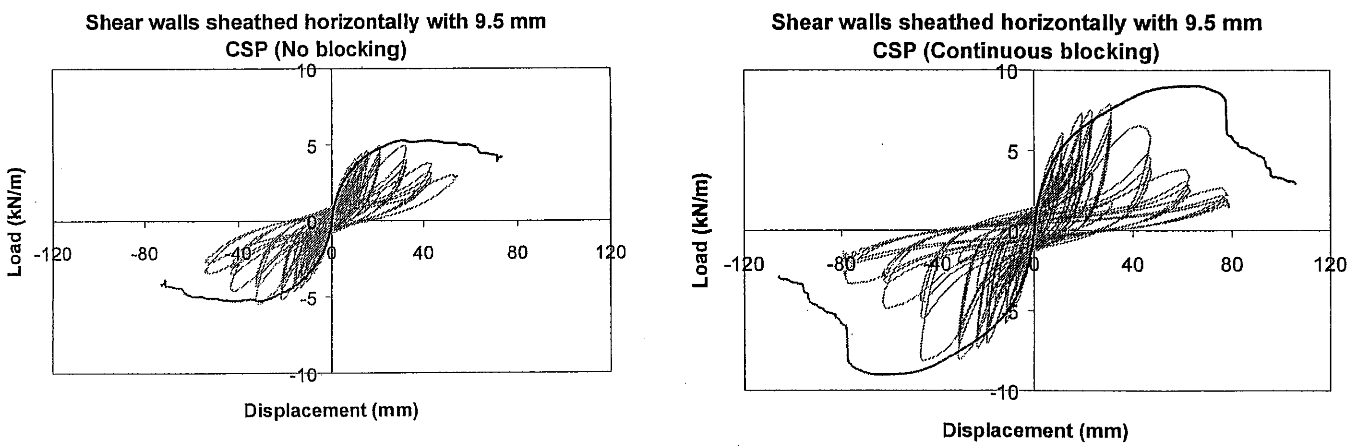

Figure 5.—Load-displacement relationships of blocked and unblocked shear walls obtained from pushover and cyclic tests.

blocked wall. The nail joints either withdrew from the studs or pulled through the panels.

Capacities of unblocked shear walls with framing members spaced 305 mm (12 in.) on center and nail spacing of 150 mm (6 in.), both at supported edges and at intermediate studs, had approximately 110 percent of the capacities of blocked shear walls (406 mm or 16 in. stud spacing) with 150 mm (6 in.) perimeter and 300 mm (12 in.) intermediate nail spacing. Ultimate displacements and secant stiffnesses of these unblocked shear walls were approximately the same as those of the reference blocked shear walls.

The above conclusions can also be made for unblocked shear walls with nail spacing 100 mm (4 in.) at supported edges and at intermediate studs. However, in these walls, a few studs split by nail joints along the unblocked horizontal joint, as shown in Figure 7. This indicated that at closer nail spacing, capacities of unblocked shear walls are governed by lumber tension strength perpendicular to grain, instead of the strengths of nail joints. Since this failure mode is not desirable, a nail spacing of 100 mm (4 in.) or less should not be encouraged in unblocked shear wall applications.

Table 2.—Summary of Forintek's test results.

Specimen	Load protocol	Stud spacing	Nail spacing (mm) Supported edges	Intermediate studs	Maximum load P	R_P[a]	Displacement D[b]	R_D[c]	Stiffness K[d]	R_K[e]
		(mm)			(kN/m)		(mm)		(kN/m/mm)	
22-02	Ramp	406	150	300	9.05		77		0.60	
29-01	Ramp	406	150	300	5.31	0.59	71	0.91	0.50	0.84
22-03	FCC93	406	150	300	7.98		50		0.91	
29-03	FCC93	406	150	300	5.23	0.66	43	0.86	0.71	0.78
31-01	Ramp	406	150	300	8.40		76		0.55	
51-01	Ramp	406	150	300	5.40	0.64	65	0.85	0.41	0.75
51-05	Ramp	305	150	150	9.36	1.11	80	1.06	0.58	1.06
51-07	Ramp	406	00	100	8.81	1.05	70	0.93	0.64	0.16
51-09	Ramp	610	100	100	5.89	0.70	68	0.90	0.57	1.04
51-21	Ramp	406	150	150	5.88	0.70	103	1.36	0.30	0.54
51-23	Ramp	406	150	150	7.53	0.90	78	1.02	0.45	0.82
31-02	FCC93	406	150	300	7.86		50		0.88	
51-02	FCC93	406	150	300	4.40	0.56	43	0.87	0.73	0.83
51-06	ISO98	305	150	150	9.18	1.17	58	1.17	0.62	0.70
51-08	ISO98	406	100	100	9.00	1.15	52	1.05	0.92	1.04
51-10	ISO98	610	100	100	5.73	0.73	49	0.99	0.60	0.69
51-22	ISO98	406	150	150	5.53	0.70	73	1.48	0.35	0.40
51-24	ISO98	406	150	150	8.58	1.09	65	1.31	0.53	0.60

Note: Walls 22-02, 22-03, 31-01 and 31-02 are blocked shear walls. 1 in. = 25.4 mm; 1 kN/m = 68.52 lb./ft.

[a] R_P = ratio of maximum load of unblocked shear wall to maximum load of blocked shear wall with the same type of load protocol.

[b] D = ultimate displacement, which is defined as the displacement at 80% of maximum load on the descending portion of the load-displacement curve.

[c] R_D = ratio of maximum displacement of unblocked shear wall to maximum displacement of blocked shear wall with the same type of load protocol.

[d] K = secant stiffness between 10% and 40% of the maximum load.

[e] R_K = ratio of secant stiffness of unblocked shear wall to secant stiffness of blocked shear wall.

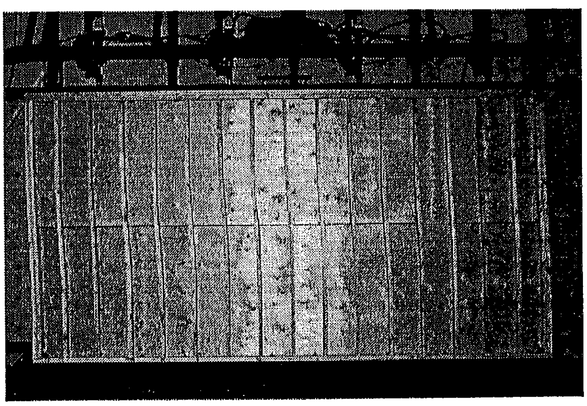

Figure 6.—Deformed shape of unblocked shear wall from wall configuration 1.

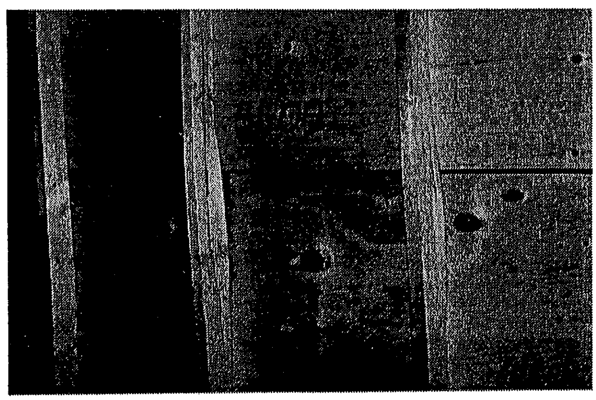

Figure 7.—Studs split along the unblocked horizontal joint with 100 mm (4 in.) nail spacing.

Wall Configuration 2

Configuration 2 of the unblocked shear wall is often used in walls with heights greater than 2.44 m (8 ft.) walls. Configuration 2 had two unblocked horizontal gaps with a 305 mm (12 in.) wide panel strip at the middle of the wall. Unblocked shear walls with nail spacing of 150 mm (6 in.) both at supported edges and at intermediate studs under wall configuration 2 showed slightly higher capacities than unblocked shear walls with nail spacing of 150 mm (6 in.) at supported edges and 300 mm (12 in.) at intermediate

Table 3.—Summary of APA's test results.

Type	Nail size	Nail spacing (mm) Supported edges	Nail spacing (mm) Intermediate studs	Panel thickness	Stud spacing	No. of tests	Ultimate load (kN/m) Min.	Ultimate load (kN/m) Max.	Ultimate load (kN/m) Avg.	Unblocked/ blocked
				---- (mm) ----						
Blocked	6d	150	300	8.0	610	15	8.4	12.4	10.6	
Unblocked	6d	150	300	8.0	406	1			8	0.75
Unblocked	6d	150	150	8.0	406	2	9.5	10.9	10.2	0.96
Blocked	6d	150	300	9.5	610	5	7.8	15.7	10.8	
Unblocked	6d	150	300	9.5	610	1			4.4	0.41
Unblocked	6d	150	150	9.5	610	1			5.5	0.51

1 in. = 25.4 mm; 1 kN/m = 68.52 lb./ft.

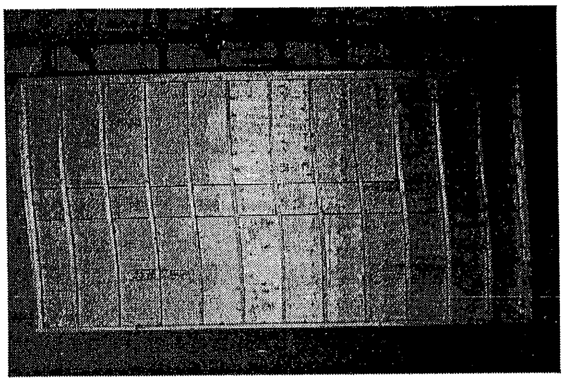

Figure 8.—Deformed shape of unblocked shear walls under wall configuration 2.

studs under wall configuration 1. Ultimate displacements of wall configuration 2 were approximately 50 percent larger than those of wall configuration 1, which is an indication of improved ductility. However, secant stiffnesses of wall configuration 2 is only about 50 percent of secant stiffnesses of wall configuration 1. The deformed shape of the unblocked wall with wall configuration 2 is shown in Figure 8.

Wall Configuration 3

Configuration 3 of the unblocked shear wall had staggered unblocked horizontal gaps at a distance of 610 mm (24 in.) from each other. Unblocked shear walls with nail spacing of 150 mm (6 in.) at supported edges and at intermediate studs (wall configuration 3), had approximately 40 percent higher load capacities than unblocked shear walls with nail spacing of 150 mm (6 in.) at supported edges and 300 mm (12 in.) at intermediate studs (wall configuration 1). Ultimate displacements of unblocked shear walls of wall configuration 3 were 10 to 50 percent larger than those of unblocked shear walls of wall configuration 1. Secant stiffnesses of the wall configuration 3 was 10 to 30 percent smaller than wall configuration 1. For wall configuration 3, a step failure pattern was observed, as shown in Figure 9.

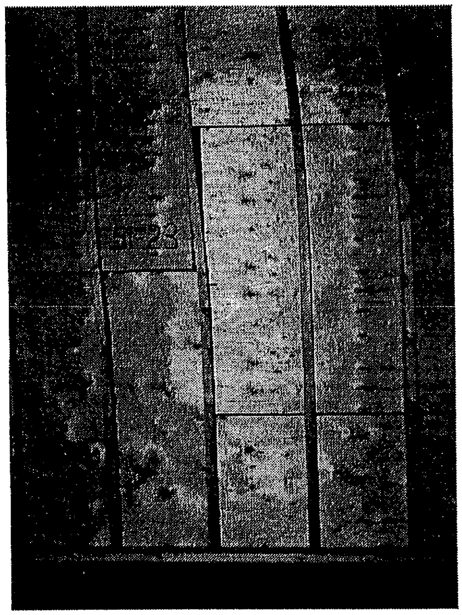

Figure 9.—Step failure pattern of unblocked shear walls under wall configuration 3.

APA Tests

Tissell (1990) conducted tests at APA on unblocked shear walls with various nail and stud spacings. Walls, 2.44 m (8 ft.) in length and height, were built with 38 by 89 mm (2 by 4 in.) kiln dried Douglas-fir lumber and 1,220 by 2,440 mm (4 by 8 ft.) plywood panels, and were tested in accordance with provisions of ASTM Standard E72.

Test results are summarized in Table 3. Typical failures of unblocked walls occurred along the unblocked horizontal joint where fasteners either withdrew from framing members or pulled through the panels.

Tissell (1990) found that the strength of unblocked shear walls was a function of nail spacing and framing spacing. Tests showed that for framing members spaced at 610 mm (24 in.) on center, the capacity of unblocked shear walls with nail spacing of 150 mm (6 in.) at supported edges and 300 mm (12 in.) at intermediate studs was about 40 percent

Table 4.—Relative load capacities of unblocked shear walls.

Nail spacing (mm)		Stud spacing (mm)			
Supported edges	Intermediate studs	305	406	508	610
150	150	2.50	1.88	1.50	1.25
150	300	2.00	1.50	1.20	1.00

1 in. = 25.4 mm.

Table 5.—Strength adjustment factor[a], J_{ub}, for unblocked shear walls.[b]

Nail spacing (mm)		Stud spacing (mm)			
Supported edges	Intermediate studs	305	406	508	610
150	150	1.0	0.8	0.6	0.5
150	300	0.8	0.6	0.5	0.4

[a] Strength adjustment factor shall only be applicable to structural wood-based panels.

[b] Specified shear strength of unblocked shear wall shall be calculated by multiplying the strength adjustment factor by the specified shear strength of a reference blocked shear wall with 610 mm stud spacing and nails spaced at 150 mm on center around panel edges and 300 mm on center along intermediate framing members.

of the capacity of blocked shear walls with 150 mm (6 in.) perimeter nail spacing. The capacity of unblocked shear walls with nail spacing of 150 mm (6 in.) both at supported edges and at intermediate studs, was about 50 percent of the capacity of blocked shear walls.

For framing members spaced at 406 mm (16 in.) on center, the capacity of unblocked shear walls with nail spacing of 150 mm (6 in.) at supported edges and 300 mm (12 in.) at intermediate studs was 75 percent of the capacity of blocked shear walls with 610 mm (24 in.) stud spacing and 150 mm (6 in.) perimeter nail spacing. The capacity of unblocked shear walls with nail spacing of 150 mm (6 in.) both at supported edges and at intermediate studs was 96 percent of the capacity of blocked shear walls.

Recommended Design Provisions

The specified shear strength for an unblocked shear wall can be determined as a percentage of the specified shear strength of a reference blocked shear wall with 150 mm (12 in.) perimeter nail spacing and 610 mm (24 in.) stud spacing. A strength adjustment factor for unblocked shear walls, J_{ub}, can be introduced as a function of framing spacing and nail spacing at supported edges and at intermediate studs.

Relative load capacities between unblocked shear walls in Table 4 were developed based on:

a. APA findings that for both 406 mm (16 in.) and 610 mm (24 in.) stud spacing, the average capacity of unblocked shear walls with 150 mm (6 in.) nail spacing at supported edges and 300 mm (12 in.) nail spacing at intermediate studs was approximately 80 percent of the average capacity of unblocked shear walls with 150 mm (6 in.) nail spacing both at supported edges and at intermediate studs, and

b. Forintek findings that for 100 mm (4 in.) nail spacing at supported edges and at intermediate studs, unblocked shear walls with 406 mm (16 in.) stud spacing had approximately 150 percent of capacities of unblocked shear walls with 610 mm (24 in.) stud spacing. This indicates that capacities of unblocked shear walls are inversely related to stud spacing.

The strength adjustment factors, J_{ub}, for unblocked shear walls in Table 5 were developed as follows. For 406 mm (16 in.) stud spacing, the average capacity of unblocked shear walls with 150 mm (6 in.) nail spacing at supported edges and 300 mm (12 in.) nail spacing at intermediate studs was approximately 60 percent the average capacity of blocked shear walls with 150 mm (6 in.) perimeter nail spacing and 406 mm (16 in.) stud spacing. It was found that blocked shear walls with 406 mm (16 in.) stud spacing had approximately 5 percent higher capacities than blocked shear walls with 610 mm (24 in.) stud spacing (Tissell 1990). Therefore, when compared to blocked shear walls with 610 mm (24 in.) stud spacing, the average capacity of those unblocked shear walls was still approximately 60 percent. This was used as the starting point in Table 5.

The remaining strength adjustment factors were developed based on relative load capacities of unblocked shear walls with a scaling factor of 0.4 (*i.e.*, 0.6/1.5 = 0.4). The values of the strength adjustment factors reasonably match APA and Forintek findings as follows.

APA Test Results

For 610 mm (24 in.) stud spacing, the capacity of unblocked shear walls with 150 mm (6 in.) nail spacing at supported edges and 300 mm (12 in.) nail spacing at intermediate studs was about 40 percent of the capacity of blocked shear walls with 150 mm (6 in.) perimeter nail spacing. The capacity of unblocked shear walls with 150 mm (6 in.) nail spacing both at supported edges and spacing at intermediate studs was about 50 percent of the capacity of blocked shear walls with 150 mm (6 in.) perimeter nail spacing. These results agree well with proposed strength adjustment factors in Table 5.

Forintek Test Results

For 305 mm (12 in.) stud spacing, the average capacity of unblocked shear walls with 150 mm (6 in.) nail spacing at supported edges and 300 mm (12 in.) nail spacing at intermediate studs was approximately 110 percent of the average capacity of blocked shear walls with 150 mm (6 in.) perimeter nail spacing and 406 mm (16 in.) stud spacing. When compared to blocked shear walls with 610 mm (24 in.) stud spacing, the average capacity of unblocked shear walls was approximately 120 percent, which suggests that the applicable strength adjust factor in Table 5 is conservative.

Stud splitting caused by nail joints loaded in tension perpendicular to grain is a brittle failure mode which is not desired. For this reason, the strength adjustment factor J_{ub} was not developed for unblocked shear walls with 100 mm (4 in.) or smaller nail spacing at supported edges and at intermediate studs due to potential splitting at the studs.

Unblocked shear walls from wall configuration 2 have lower capacities and secant stiffnesses than corresponding unblocked shear walls from wall configuration 1.

Unblocked shear walls with 150 mm (6 in.) nail spacing at supported edges and at intermediate studs from wall configuration 2 can be conservatively (with the exception of secant stiffness) treated as unblocked shear walls with nail spacings of 150 mm (6 in.) at supported edges and 300 mm (12 in.) at intermediate studs.

Table 5 was published in the 2001 edition of CSA Standard O86.1 (Canadian Standard Association 2001).

Conclusion

Three types of unblocked shear walls were tested under monotonic and reversed cyclic tests. A strength adjustment factor for unblocked shear walls, J_{ub}, was proposed to correlate specified shear strength of an unblocked shear wall to specified shear strength of a blocked shear wall of the same panel grade and thickness with 150 mm (6 in.) perimeter nail spacing. The strength adjustment factor J_{ub} is a function of framing spacing and nail spacing at supported edges and at intermediate studs.

Future Work

The strength adjustment factors for unblocked shear walls in this paper are applicable to walls with 2.44 m (8 ft.) height. Work is in progress for extending these findings to walls with greater height and to double-sided unblocked shear walls. Although consistency in ultimate displacements is considered in recommending design provisions, dissipated energy shall also be considered in future studies. Finally, the deflection formula for unblocked shear walls should also be implemented in design codes.

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News

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APA Sturd-I-Frame

APA–The Engineered Wood Association has recently completed full-scale destructive testing and analysis of narrow wall frame sections that are designed to brace against high winds and earthquakes around garages and other large openings. The designs are the subject of APA's new publication, *Sturd-I-Frames for Narrow Wall Bracing*, which describes Sturd-I-Frame®, a site-built wall-frame section that provides the strength and stiffness of a bracing unit and offers options for engineered designs.

While builders, homeowners, and designers want narrow wall segments adjacent to garage doors and other large openings, the use of 16 to 24-in. wide wall sections does not meet the prescriptive bracing requirements of the building code. Nor are such narrow wall segments wide enough to be designed as engineered shear walls because of their high aspect ratios (height-to-width ratio).

The Sturd-I-Frame system gives builders and homeowners a solution that allows for the architecturally preferred narrow walls while providing necessary strength and stiffness. The connections allow the Sturd-I-Frame to act as a moment-resisting "portal frame." The Sturd-I-Frame system can also be used for engineered applications where shear walls would normally be required. Design values are also available in the new publication.

The publication is available in PDF format at www.apawood.org or can be obtained from APA–the Engineered Wood Association, Publications Dept., P.O. Box 11700, Tacoma, WA 98411-0700.