Proceedings of the

8^{th} World Conference on Timber Engineering

WCTE 2004

Volume I: Presentations held on Monday
Volume II: Presentations held on Tuesday and Thursday
Volume III: Presentation held on Wednesday and all posters

Lahti, Finland
June 14-17, 2004

Local Organisers

Finnish Association of Civil Engineers **RIL**
VTT Technical Research Centre of Finland
Wood Focus

ISSN 0356-9403
ISBN 951-758-442-3

Narrow Shear Walls - A Portal Frame Solution

Thomas G. Williamson, P.E.
Vice President, Quality Assurance and Technical Services
APA - The Engineered Wood Association
Tacoma, Washington, U.S.A.

Borjen Yeh, Ph.D., P.E.
Director, Technical Services Division
APA - The Engineered Wood Association
Tacoma, Washington, U.S.A.

1. Summary

In the past 5 years, there has been an unprecedented amount of research in the U.S. related to the performance of narrow shear walls or bracing units. Confusion has existed regarding how to properly design and construct narrow walls (defined as having an aspect ratio of greater than 2:1). In order to develop a solution that provides adequate strength and stiffness for use as bracing in traditional North American light-frame wood construction for narrower walls, a portal frame design was developed by APA - The Engineered Wood Association. Monotonic and cyclic testing has been conducted on the APA portal frame design. Recommended design values for engineered use of the portal frames have also been developed and these have been compared to existing prescriptive bracing wall designs. This paper will review this testing program and provide guidance for the design of these narrower wall elements to resist both wind and seismic forces.

Keywords: Narrow shear walls, Portal frame, Bracing units

2. Introduction

North American light-frame wood construction frequently requires wall elements that are as narrow as 16 inches adjacent to two or three car garage door openings. In addition, with the homeowners' interest in having multiple large open view windows, additional narrow wall elements are often introduced and thus the need for improved designs of narrow walls has been recognized by the wood engineering and construction industries.

In the U.S., there are 2 options when narrow shear walls are desired. The first option is to follow the prescriptive requirements given in the 2003 International Residential Code (IRC) [1] provided a) the seismic design category is not higher than D_2 and/or the wind speed is less than 177 km per hour (110 miles/hr) and b) when structural panels (plywood and OSB) are used as wall sheathing. It should be noted that as part of the IRC prescriptive requirements, the structure is required to be fully sheathed with structural panels on all sheathable areas of all exterior walls and interior brace wall lines. In addition, the code requires the use of minimum specified corner-framing details intended to provide additional structural rigidity.

The minimum width for shear walls per the 2003 IRC is 61 cm (24 in.) for a 244 cm (8-ft) tall wall (aspect ratio of 4:1) if the openings next to such walls are limited to 0.65 times the story height. These 4:1 aspect ratio walls can be used in any of 3 stories and have no specific hold-down requirements except for the code specified corner framing. When constructed in accordance with the 2003 IRC requirements, the structure is considered to meet the code and does not require engineering. These prescriptive IRC narrow walls represent the minimum code requirements and can serve as a benchmark for other narrow walls on a comparative basis. The second option, for design cases beyond the IRC prescriptive limitations, requires an engineering design per the 2003 International Building Code (IBC) [2].

With an intent to provide alternatives to the IRC prescriptive solution and the IBC engineering solution, APA has conducted a series of cyclic shear wall tests using a portal-frame design [4,5]. Results of those tests are described as follows.

3. Prescriptive alternatives

Since the IRC 4:1 aspect ratio walls are the currently acceptable baseline, tests were conducted on a 41 cm (16-in.) wide portal frame design with similar end restraints (corner-framing details). A total of 8 tests were conducted in 4 configurations (2 replicates for each configuration): a) 2 control assemblies (Walls 1 and 2) constructed in accordance with the current IRC 4:1 aspect ratio walls without hold-downs, b) 2 control assemblies (Walls 3 and 4) constructed in accordance with the current IRC 4:1 aspect ratio walls with hold-downs, c) 2 one-side-sheathed 41 cm (16-in.) wide portal frame design without hold-downs (Walls 5 and 6), and d) 2 one-side-sheathed 41 cm (16-in.) wide portal frame design with hold-downs (Walls 7 and 8). The walls tested were 244 cm (8 ft) in height and 366 cm (12 ft) in length, as shown in Figure 1. The use of hold-downs in Configurations (b) and (d) was intended to simulate the upper bound of end restraints provided by the fully sheathed sidewalls, header, and dead weight from above.

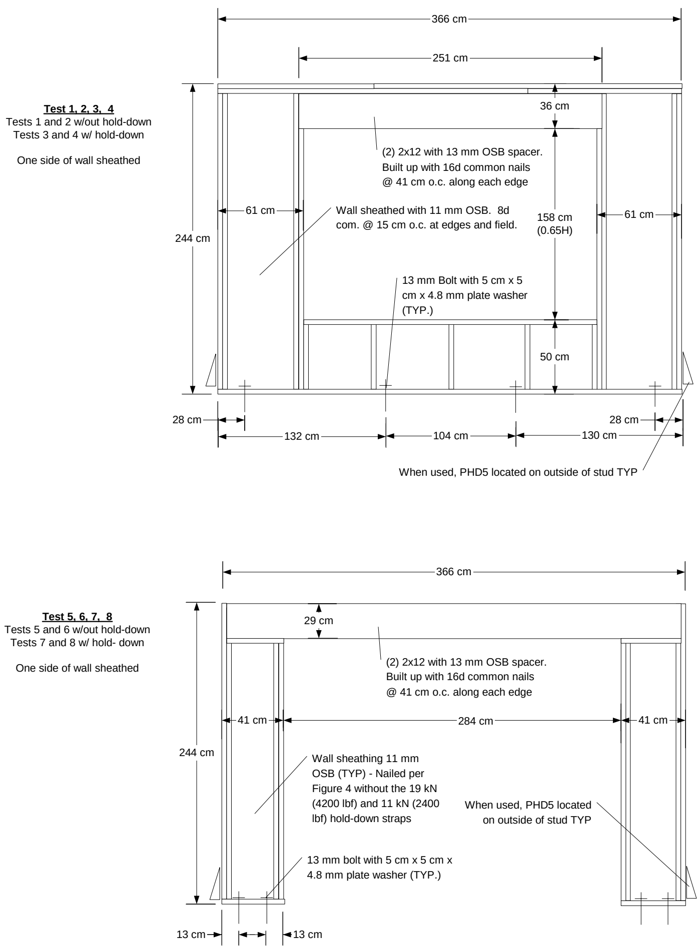

Figure 1. Tested shearwall assemblies

3.1 Materials

Dry (moisture content of 19% or less) 2x4 No. 2 Douglas-fir (DF) lumber was used for the shear wall framing. The header was built up using two pieces of 2x12 No. 2 DF on the faces and a 13 mm (1/2-in.) oriented strand board (OSB) spacer in the core to create a header surface that was flush with the 2x4 framing. The wall sheathing was composed of 11 mm (7/16-in.) APA Rated OSB Sheathing with a span rating of 24/16. Nails used for attaching wood structural panel sheathing to framing were 8d common (3.3 mm diameter x 6.4 cm long). Nails used for stitch nailing the double end studs were 10d common (3.8 mm x 7.6 cm), spaced 61 cm (24 in.) on center per the building code. Hold-down devices used in Configurations (b) and (d) were Simpson Strong Tie PHD5's, which were installed on the outside of the end studs.

The sill plate was fastened to the test frame by 13 mm (1/2-in.) diameter sill bolts with 5 cm (2-in.) x 5 cm (2-in.) x 4.8 mm (3/16-in.) plate washers. Placement of the sill anchorage is as specified by the code, and is shown in Figure 1. A Simpson Strong Tie LSTA 24 strap (3.2 cm wide x 61 cm long, 20-gage steel, and using 14 - 10d common nails) rated at 4.4 kN (1000 lbf) was used in the backside of the narrow walls to provide vertical continuity for loads normal to the sheathing surface and to provide reinforcement for lateral loadings.

3.2 Test Set-up and Procedure

For each wall, lateral loads were applied by a load head beam-to-header connection using a combination of bolts and lag screws. The OSB sheathing was free to rotate without bearing on the foundation frame or load beam above. Linear potentiometers (LP's) were used to measure displacement due to 1) crushing and uplift at double end studs, 2) sliding of the sill plate, and 3) global lateral displacement at the upper top plate at the end away from the load head. The applied load was measured with a load cell located between an MTS hydraulic actuator and the load head.

3.3 Cyclic Load Protocol

The cyclic load displacement protocol for these tests followed the sequential phased displacement (SPD) method, as developed by the Structural Engineers Association of Southern California (SEAOSC) [6]. The first major event (FME) was set at 3 cm (1.2 in.) based on experience.

3.4 Test Results

A summary of the test results is shown in Table 1 and Figure 2 based on the absolute average values of the positive and negative displacement excursions. The effective wall stiffness, K, as a measure of global behavior of the wall, is calculated by dividing the lateral shear force measured at the top edge of the frame by the backbone curve displacement of the top edge of the frame. The effective wall stiffness includes all variables contributing to total wall displacement, e.g. nail slip, hold-down slip, end stud elongation, etc.

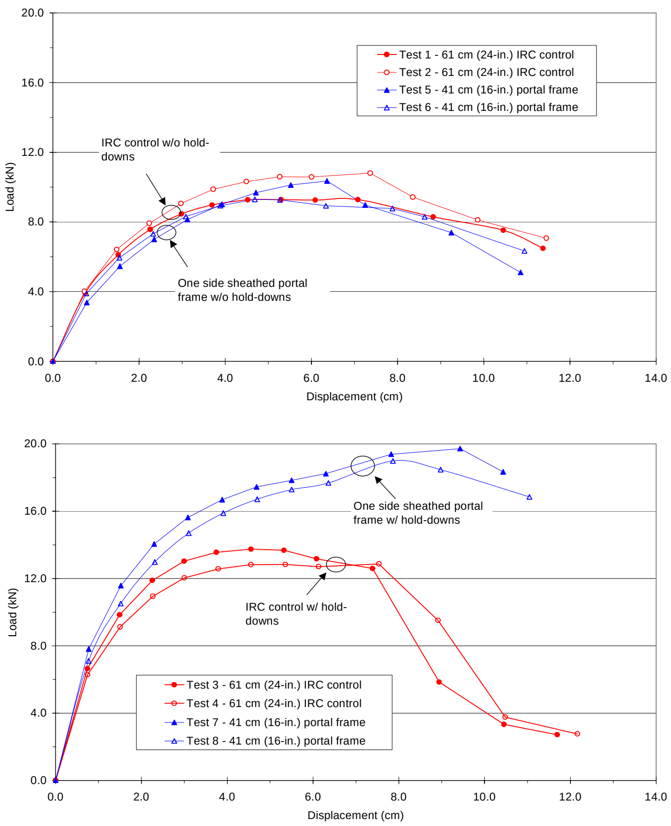

Figure 2. Test results

3.5 Failure Modes

Walls 1-4 had classical shearwall failure where the failure was dominated by the nailed connection between sheathing and framing. Some nail fatigue was observed in Walls 1-4, which is common for wood structural panel shearwall tested in accordance with the SPD protocol. Walls 7 and 8 (portal frame with hold-downs) had a similar failure mode as Walls 1-4, while the occurrence of OSB tearing was common for Walls 5 and 6 (portal frame without hold-downs). The OSB tearing occurred after the metal straps on the backside failed due to fatigue.

Table 1. Summary of test results (data is the mean of +/- excursions)

				Stiffness			Maximum	
	Aspect Ratio	End Restraint	Wall No.	K kN/cm	Load kN	Def cm	Load kN	Def cm
IRC control (currently permitted IRC braced wall)	4:1	No	1	5.22	3.94	0.76	9.44	5.8
			2	5.48	4.02	0.74	10.81	7.4
			Mean	5.34	3.98	0.74	10.12	6.6
		Yes	3	8.98	6.65	0.74	13.75	4.9
			4	9.28	6.29	0.74	12.97	6.0
			Mean	9.12	6.47	0.74	13.36	5.5
Portal Frame One Side Sheathed	6:1	No	5	4.31	3.38	0.79	10.35	6.4
			6	5.04	3.90	0.76	9.41	5.5
			Mean	4.68	3.64	0.79	9.88	5.9
		Yes	7	10.17	7.81	0.76	19.72	9.4
			8	9.25	7.10	0.76	18.99	7.9
			Mean	9.70	7.46	0.76	19.35	8.6

3.6 Bracing Comparison

The portal frame walls without hold-downs (Walls 5 and 6) demonstrated performance similar to that of the currently accepted 4:1 aspect ratio walls without hold-downs (Walls 1 and 2), except that the initial stiffness and the displacement associated with the maximum load were about 10% lower. These exceptions occurred in the case where no restraints were provided by a fully sheathed sidewall, which would not be expected in accordance with the code. On the other hand, the portal frame walls with hold-downs (Walls 7 and 8) demonstrated better performance than the currently accepted 4:1 aspect ratio walls with hold-downs (Walls 3 and 4). The use of hold-downs simulated the upper bound of end restraints provided by the fully sheathed sidewalls, header, and dead weight from above. Since the tests without hold-downs represent the lower bound of end restraints, the envelopes encompassing the tests with and without hold-downs, as shown in Figure 3, indicate that the portal frame walls (aspect ratio 6:1) have comparable performance with the current IRC walls (aspect ratio of 4:1).

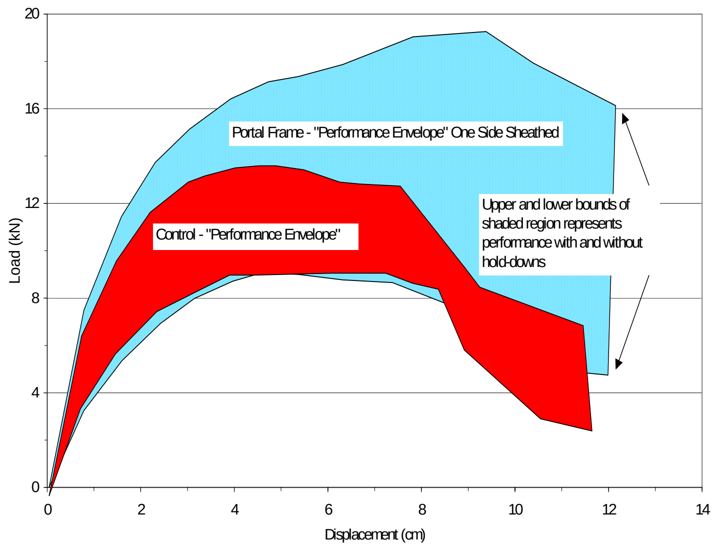

Figure 3. Performance comparison

4. Engineering Solutions

While the APA portal frame design was envisioned primarily for use as bracing in conventional light frame wood construction, it can also be used in engineered applications. The portal frame, as shown in Figure 4, is technically not a narrow shearwall because it transfers shear by means of a moment resisting frame. A continuous header extended over the walls adjacent to the opening is integral in the function of the portal frame. Thus the effective frame width is more than just the wall segment, as it also includes the header length that extends beyond the sheathed wall segment. For this shear transfer mechanism, the wall aspect ratio requirements of the code do not technically apply to the wall segment of the APA portal frame. In order to derive values for engineering design, a series of cyclic portal frame tests were conducted by APA on 41 cm (16-in.) and 61 cm (24-in.) walls with wall heights of 244 and 305 cm (8 and 10 ft).

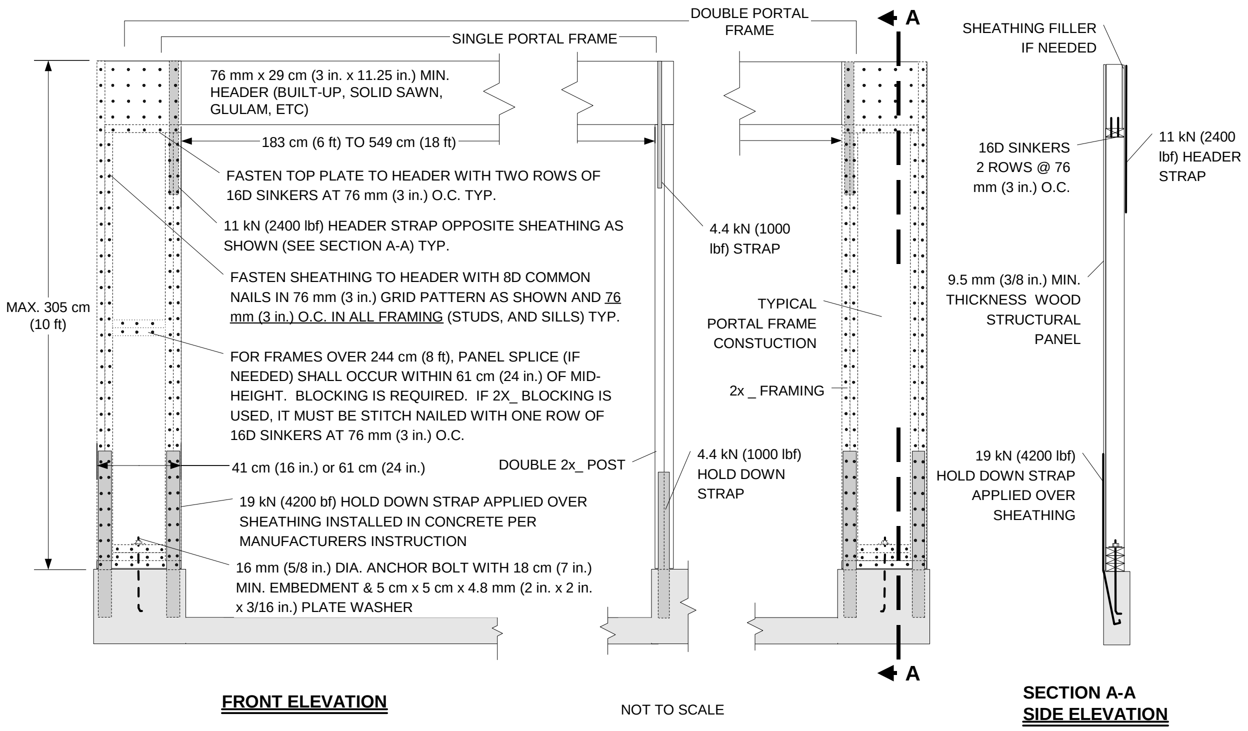

Figure 4. Construction details for the APA portal frame design

Details of these portal frame tests are documented in APA Reports T2002-46 [7] and T2003-11 [8], but not presented here due to the length limitation of this paper. However, results from SPD cyclic tests supported the allowable design values given in Table 2 for engineering design. It should be noted that the basis for these allowable design values are based on test results obtained from portal frame walls attached to a rigid test frame. Therefore, these design values should be limited to portal frames constructed on rigid foundations, such as a concrete foundation, stem wall, or slab.

5. Final Remarks

The engineering solution given in Section 4 was submitted to the IBC Structural Committee for inclusion in the 2006 IBC and received tentative approval subject to final approval by the IBC Code Committee. APA plans to address the issue of narrow walls in conjunction with raised floor construction in 2004.

Table 2. Allowable design values for APA portal frame on rigid foundation [(a, b, c, d)]

Minimum Width (cm)	Maximum Height (cm)	Ultimate Shear Strength (kN)	ASD Allowable Design Values			Load Factor
			Shear (kN)	Stiffness (kN/cm)	Deflection (cm)	
41	244	12.37	4.45	5.43	0.81	2.8
	305	9.70	2.67	2.63	1.02	3.6
61	244	20.99	7.56	9.28	0.81	2.8
	305	16.15	4.45	5.08	0.86	3.6

(a) Design values are based on the use of Douglas-fir or southern pine framing. For other species of framing, use the specific gravity adjustment factor = [1 - (0.5 - SG)], where SG = specific gravity of the actual framing. This adjustment shall not be greater than 1.

(b) For construction as shown in Figure 4.

(c) Values are for a single portal frame. For multiple portal frames, allowable design values can be multiplied by number of frames (e.g., two = 2x, three = 3x, etc).

(d) Interpolation of design values between 244 cm (8 ft) and 305 cm (10 ft) heights is permitted.

The prescriptive alternative given in Section 3 was also proposed by APA for adoption into the 2006 IRC and final approval is pending. The proposed prescriptive alternative will be limited to the first story of a two-story building next to garage door openings in Seismic Design Categories A through C as defined by the IRC. The aspect ratio will be limited to 6:1 with the maximum wall height, as measured from the top of header to sill plate, of 305 cm (10 ft). The clear span of the header between the inner studs of each panel shall be no more than 549 cm (18 ft) in length. A strap with an uplift capacity of not less than 4.4 kN (1000 lbf) shall be installed to fasten the header to the side of the inner studs opposite the sheathing. It should be noted that even though this prescriptive alternative has not been adopted by IRC, several local code jurisdictions in the U.S. have adopted the provisions in the state building codes.

6. References

[1] IRC, *International Residential Code for One and Two Family Dwellings*, International Code Council, Falls Church, VA, 2003.

[2] IBC, *International Building Code*, International Code Council, Falls Church, VA, 2003.

[4] APA, Testing a Portal Frame Design for use as Bracing in Fully Sheathed Structures, *APA Report T2003-48*, APA - The Engineered Wood Association, Tacoma, WA, 2003.

[5] APA, Cyclic Testing of Portal Frame Bracing for Garages with No Hold-Down Devices, *APA-Report T2003-1*, APA - The Engineered Wood Association, Tacoma, WA, 2003.

[6] SEAOSC, *Standard method of cyclic (reversed) load test for shear resistance of framed walls for buildings*, Structural Engineers Association of Southern California, Whittier, CA, 1997.

[7] APA, Cyclic Evaluation of APA Sturd-I-Frame for Engineered Design, *APA Report T2002-46*, APA - The Engineered Wood Association, Tacoma, WA, 2002.

[8] APA, Cyclic Evaluation of APA Sturd-I-Frame with 10-ft Height and Lumber Header, *APA Report T2003-11*, APA - The Engineered Wood Association, Tacoma, WA, 2003.