Earthquake resistance of shearwalls with oversize sheathing panels

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ABSTRACT

This paper presents the results from a study on the seismic resistance of wood based shear walls with nonstandard size oriented strand board sheathing. Comparisons made amongst shear walls tested under monotonic, cyclic and dynamic loads indicates that walls sheathed with a single nonstandard size panel achieved a substantial increase in both stiffness and strength, and were better able to survive the chosen earthquake input than those constructed with multiple standard size panels.

INTRODUCTION

Single family residential wood frame buildings, in general, have a reputation of excellent performance in earthquakes, which was confirmed during recent earthquakes. Many larger multi-storey buildings with large openings and irregular plan layout, however, have performed relatively poorly, resulting in many fatalities and very high financial losses. This has prompted many researchers to once again examine the performance of shear walls under extreme seismic and wind loading.

A considerable amount of experimental work has been done in the past on the structural behaviour of wood based shear wall systems, including full scale testing of walls (with and without openings) and buildings under monotonic, cyclic, pseudo dynamic and dynamic lateral load conditions. Almost all of these research efforts have focused on walls and diaphragms built with standard 1.2 × 2.4 m size panels nailed to closely spaced dimension lumber studs. Researchers have repeatedly identified the discontinuity between panels as one of the most important factors affecting the performance of the walls, which implies that significant gains in the in-plane shear capacity may be achieved by using integral panels. Some oriented strand board (OSB) mills currently produce panels of up to 3.3 × 7.3 m in size, which are subsequently cut into standard size panels (1.2 × 2.4 m) for conventional building applications. This study was initiated to explore the benefits of using such nonstandard full panels in conventionally framed shear walls, especially in regions where earthquake loads are a major concern for wood frame buildings.

EXPERIMENTAL STUDIES

In the first phase of this study, a group of 2.4 × 7.3 m shear walls sheathed with single oversize panel were tested under monotonic and quasi-static cyclic loading conditions (Lam et al. 1997, He et al. 1998, 1999). Comparison of test results with those from the walls sheathed with standard size panels indicated an increase in load carrying capacity of (>100%) and stiffness (>163%) if internal seams were eliminated and nails were relocated to the outer edges. However, the total displacement at failure and the post-peakload displacement were reduced significantly, which raised some concerns about the ductility of the walls and how the earthquake resistance would be affected by the changes in stiffness and failure displacement. Thus, the second phase of study was carried out to investigate and determine if similar benefits could be achieved by using oversize panels under simulated seismic loading conditions.

A total of 12 shear walls, 2.4 × 2.4 m in dimension, were tested under various loading conditions (Table 1). The wall dimensions were dictated by the limitations of the shake table. No. 2 and better Spruce-Pine-Fir 38 × 89 mm dimension lumber was used for all the framing members, which were connected by pneumatically driven 76 mm common nails. The stud members were spaced at 400 mm on centre. The top plate and the end studs consisted of double members while the bottom plate and the interior studs consisted of single members. Performance rated W24 oriented strand boards (CSA,

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1992), 9.5 mm thick, were used as sheathing panels. The panels were connected to the framing members with pneumatically driven 50 mm spiral nails at 152 mm or 76 mm spacings along the panel edges and a standard spacing of 305 mm along the interior studs. The conventional size panels (layout A) were staggered and oriented with their long axes parallel to the length of the wall. Continuous blocking was used along the mid-height panel seams.

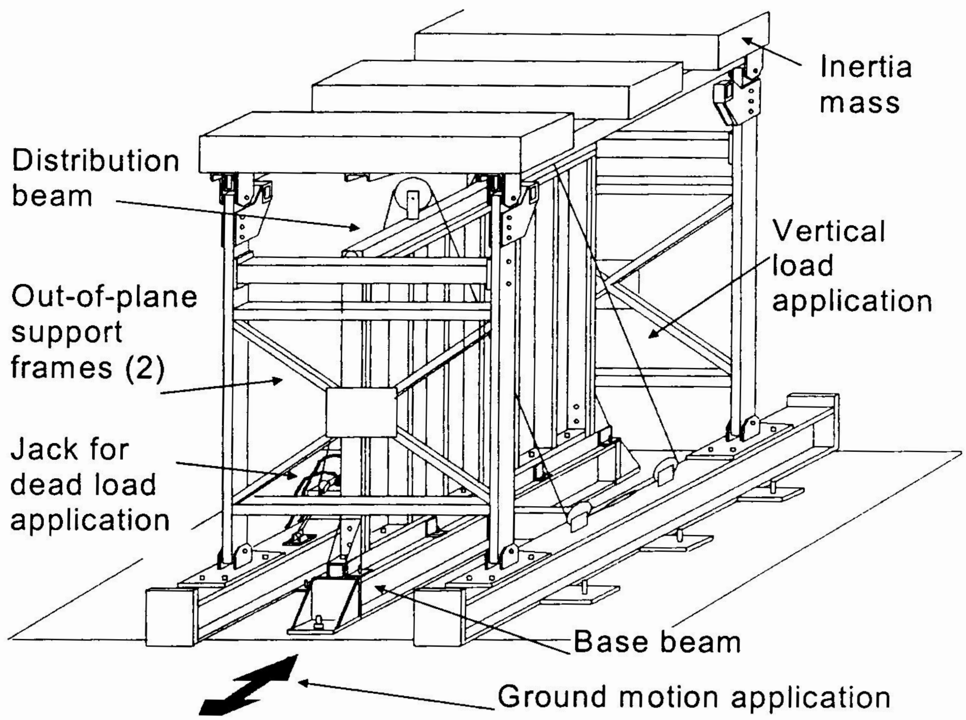


Fig. 1 Shake table setup with 2.4m long wall installed

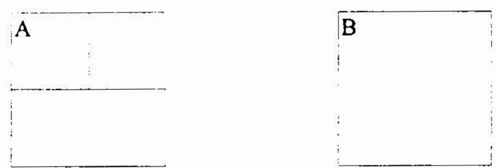
Both monotonic and cyclic tests were carried out on the test setup used in the first phase of the study (Lam et al. 1997) with a modification to suit the shorter length of test wall specimens. The loading rate for the monotonic tests was 7.8 mm/min, based on recommendations in the ASTM standard (ASTM 1991). For the cyclic tests, a newly proposed protocol, developed by He et al. (1998), was used. The older long sequence cyclic test protocols were found to cause extensive yielding in the nails during the early stages of the test, leading to nail fractures due to low cycle fatigue so that the wall often could not reach the expected maximum load carrying capacity. It was found, however, that such failures rarely occurred under real or simulated seismic conditions. The new protocol consisted of two groups of cycles, three identical cycles in each group, and one final unidirectional loading (push-over) until the wall failed. The amplitudes of these cycle groups corresponded to the displacement at 50% and 80% of the maximum load obtained from the monotonic shear wall tests.

All the shear walls were tested with a constant distributed vertical load of 9.12 kN/m, which represents the weight of one storey (Lam et al. 1997, Durham 1998). The dynamic tests were carried out on the University of British Columbia's earthquake shake table using a specially constructed test frame for 2.4 × 2.4 m walls (Dolan 1989) (Fig. 1). The frame was modified for this study to include a pulley system that imposed a relatively constant dead load, consistent with the static tests, on the top of test wall. Conventional hold downs were used to prevent overturning of the walls. For the shake table tests, the east-west acceleration record of the 1992 California Landers Earthquake, recorded at Joshua Tree Station, was used (Fig. 2). The record contained two segments of high amplitude of acceleration with long duration. These characteristics were found from the previous studies to be particularly severe and typically caused failure in 2.4 m shear walls. Furthermore, the natural period of an undamaged wall was calculated to be about 0.2 - 0.3 s, which coincided with the period range containing high energy input in the Joshua record (Latendresse and Ventura 1995). A peak ground acceleration of 0.35g was chosen as a reasonably realistic input for a wall. Also, this was the level of shaking required to fail the walls, according to preliminary analyses.

Table 1 Shear wall test program

Test No.	Wall Size (m) H x L	Panel size (m)	Panel layout (see below)	Lateral loading protocol	Nail spacing along panel edges (mm)	Total no. of nails used
1	2.4 × 2.4	1.2 × 2.4	A	Monotonic	152	157
2	2.4 × 2.4	1.2 × 2.4	A	Cyclic	152	157
3	2.4 × 2.4	2.4 × 2.4	B	Monotonic	152	109
4	2.4 × 2.4	2.4 × 2.4	B	Cyclic	152	109
5	2.4 × 2.4	2.4 × 2.4	B	Monotonic	76	173
6	2.4 × 2.4	2.4 × 2.4	B	Cyclic	76	173
7	2.4 × 2.4	1.2 × 2.4	A	Dynamic	152	157
8	2.4 × 2.4	1.2 × 2.4	A	Dynamic	152	157
9	2.4 × 2.4	2.4 × 2.4	B	Dynamic	152	109
10	2.4 × 2.4	2.4 × 2.4	B	Dynamic	152	109
11	2.4 × 2.4	2.4 × 2.4	B	Dynamic	76	173
12	2.4 × 2.4	2.4 × 2.4	B	Dynamic	76	173

Panel layout:



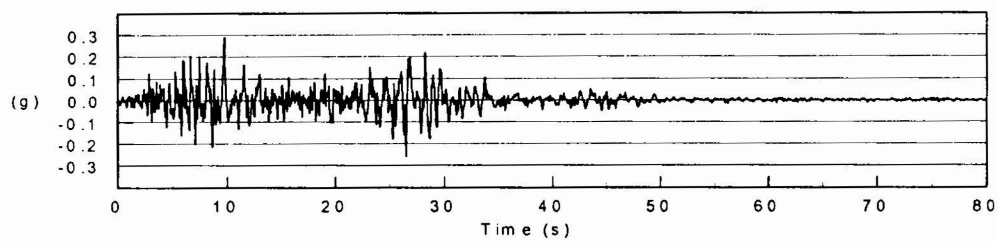


Fig. 2 Earthquake acceleration input for dynamic tests

RESULTS AND DISCUSSIONS

The most important results are presented in Table 2. P_{max} is the maximum load carrying capacity of a shear wall. Δ_u is the wall displacement at maximum load. Δ_{yield} is the yield slip defined as the wall displacement at half of maximum load. S_u is the ultimate wall shear strength, defined as $S_u=P_{max}/L$, while G' is the shear stiffness: $G'=(P_{max}H)/(2L\Delta_{yield})$. D is defined as the wall's ductility factor: $D=\Delta_u/\Delta_{yield}$. N is the number of panel nails. L and H are the length and height of the wall, respectively.

For all the shear walls, there was good agreement between the maximum load values for each type of wall, whether tested monotonically, cyclically or dynamically. Similar to past research findings (Lam et al. 1997), substantial gains in load carrying capacity were realized by substituting the regular panels with a single panel. Furthermore, very similar displacement capacities at ultimate load were observed. Monotonic test results also indicate a substantial increase in stiffness in shear walls with oversized panels as compared to regular panel walls (Fig. 3 (a)).

During the cyclic tests, once the newly proposed cyclic test protocol was used, no nail fatigue failures were observed, which was a governing failure mode in walls tested using the older long sequence cyclic test protocols, and realistic degradation characteristics in strength and stiffness were observed. This was also evident in the dynamic tests. Both monotonic and cyclic test protocols produced similar load-deflection envelope curves and failure modes (Fig. 3 (b)). The applied new test protocol produced energy dissipation values in the same magnitude as the simulated earthquake loading. Shear walls with smaller nail spacing dissipated almost twice as much energy as walls with standard nail spacing whether tested cyclically or dynamically with earthquake input. Static monotonic and cyclic test results indicated that, unlike 2.4 ×

7.3 m shear walls, 2.4 × 2.4 m shear walls sheathed with a single oversize panel did not show a significant decrease in failure displacement, when compared to conventionally sheathed shear walls, although an increase in strength and initial stiffness was achieved. This may be attributed to the use of conventional hold downs in the current study, which allowed the walls to more fully develop their ductility.

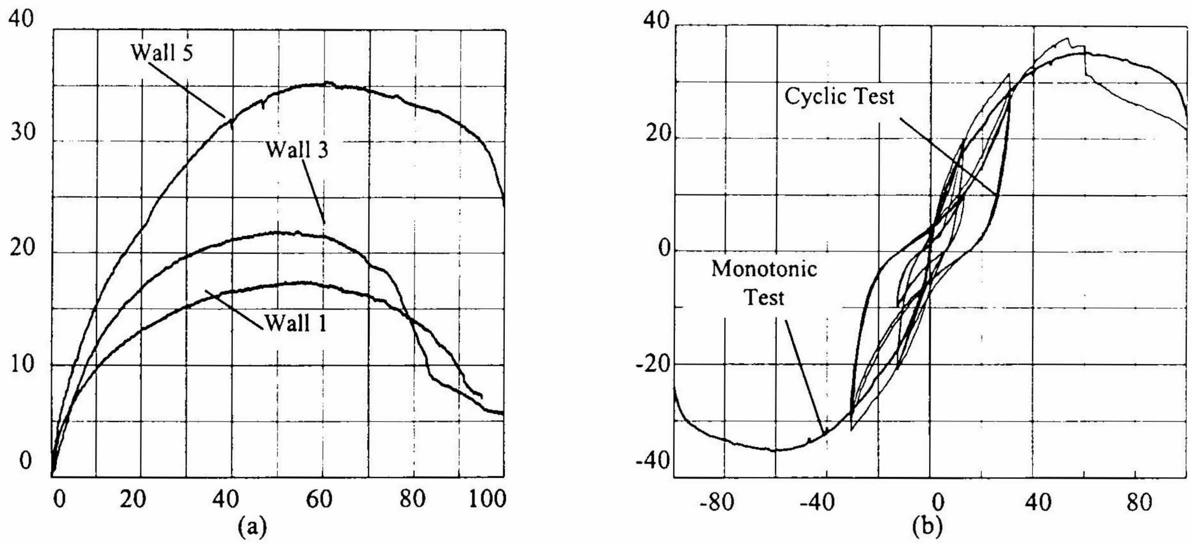


Fig. 3 Typical load vs. top wall displacement curves for statically loaded shear walls
(a) Monotonic curves for 2.4 m walls 1 (regular panels), 3 (oversize panels, regular nail spacing) and 5 (oversize panels, reduced nail spacing); (b) New cyclic test protocol cyclic load-displacement curve and monotonic envelope for 2.4 m wall 6 (oversize panels, reduced nail spacing).

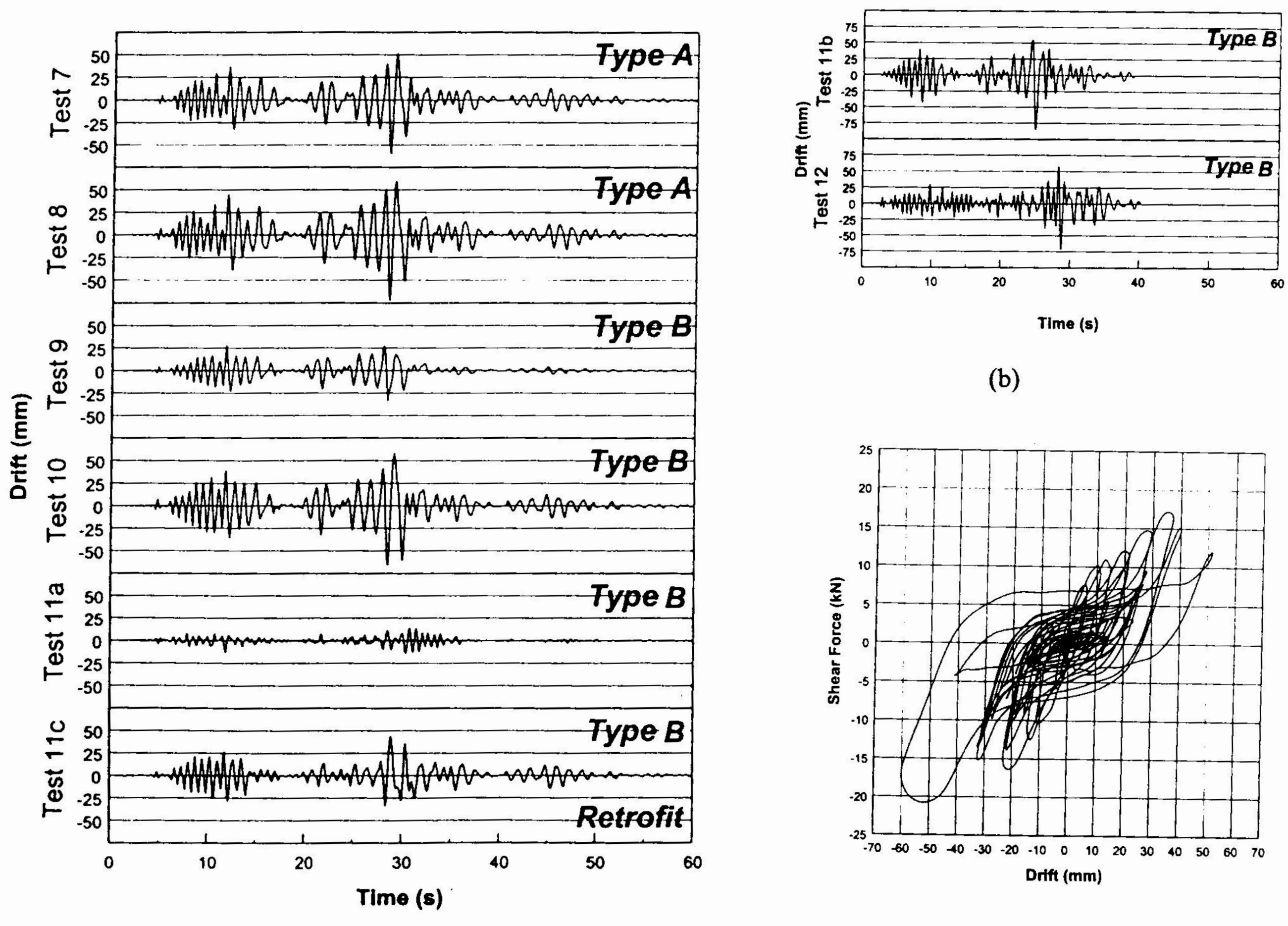
Table 2 Summary of shear wall test results

Static Tests							
Wall	P_{max} (kN) [a]	Δ_u (mm)	Δ_{yield} (mm)	S_u (kN/m)	G' (MN/m)	D	N
1	17.38	57.49	8.26	7.12	1.05	6.9	157
2	+20.42[b]	78.58	21.89	-	-	-	157
3	21.94	54.63	9.14	8.99	1.20	6.0	109
4	+21.72[b]	51.24	17.82	-	-	-	109
5	35.40	60.85	12.87	14.51	1.38	4.7	173
6	+38.01[b]	53.07	24.46	-	-	-	173

Dynamic Tests					
Wall	Peak[c] top of wall (absolute) acceleration (g)	Peak[c] drift (mm)	Peak[c] base shear (kN)	Natural Frequency (Hz)	N
7	0.33	53.42	20.35	4.2	157
8	0.32	61.64	20.42	4.0	157
9	0.34	45.14	21.98	4.6	109
10	0.33	60.84	19.88	4.2	109
11a[d]	0.37	43.87	21.54	-	173
11b[e]	0.50	76.13	30.86	-	173
11c	0.38	61.76	24.28	-	173
12[e]	0.61	83.97	38.17	4.5	173

[a] + ⇒ extension of the hydraulic cylinder.
[b] ultimate capacity was not reached in negative cycles.
[c] all peaks are expressed as magnitudes.
[d] wall 11a did not reach failure.
[e] the input was stopped early in these tests.

Under dynamic loading, an excellent agreement was found between base shears measured in dynamic tests and ultimate loads in static tests (Table 2). The stiffer walls with single sheathing and reduced nail spacing were found to experience higher accelerations, less drift (relative displacement of the top of the wall vs. the bottom) and higher peak loads (Fig. 4 (a)). This observation was consistent with prior testing and analysis (Durham et al. 1997). One good example was wall 11. It was first subjected to an earthquake excitation, scaled to a peak acceleration of approximately 0.35g (test 11a, Fig. 4 (a)), which left it virtually undamaged. The wall was subsequently subjected to a 0.52g earthquake (test 11b, Fig. 4 (b)), which caused severe damage. The damaged wall was then repaired and subjected to another 0.35g earthquake (test 11c, Fig. 4 (a)). The response was similar to a more flexible wall, as observed for walls 7-10. These tests suggested that a severely damaged shear wall constructed with a single oversize panel and reduced nail spacing can be retrofitted to regain a level of performance expected from a shear wall with regular panels in a significant earthquake. In Fig. 4 (c), the hysteresis loops in test 7 show the relatively small number of large loops in elastic as well as in inelastic regions, which quantifies the validity of using a small number of cycles in new cyclic test protocol. A reduction in stiffness is observable, as the wall deteriorated severely by flatter gradients of loops.



(a)

(c)

Fig. 4 Dynamic time-drift histories of shear walls under earthquake excitation
(a) Tests subjected to a 0.35g peak ground acceleration; (b) Tests subjected to a 0.52g peak ground acceleration; (c) Hysteresis loops of test 7.

To determine if the new cyclic test protocol is reasonable for use in dynamic modeling, the energy dissipated in cyclic tests was compared to that in dynamic tests. It was found that the total energy dissipation in a cyclic test was generally two times smaller than that in a dynamic test. This implies that the new cyclic test protocol could be extended by adding a few extra cycles in the intermediate displacement range and by cycling through each displacement to reach the stabilized envelope curve.

The dominant failure modes in all loading types were either nails pulling out of the frame or nails pulling through the sheathing. The observed failure modes served to verify that the behaviour of nailed timber shear walls is governed by the behaviour of nail connectors. Due to the higher overturning moment of the 2.4 × 2.4 m shear walls, the applied vertical dead load plays an increasingly important role in preventing uplift of the wall corners. The use of hold down brackets was shown to be crucial to achieve the desired racking resistance of a wall.

CONCLUSIONS

Shear walls constructed with nonstandard oversize oriented strand board sheathing panels were successfully tested under monotonic, cyclic and dynamic loading conditions using developed test methods and existing test facilities. The following conclusions can be drawn from the study:

(1) A substantial increase in both stiffness and lateral load carrying capacity in shear walls with oversized panels can be achieved when compared to regular panel walls.

(2) A newly proposed shorter cyclic protocol was shown to effectively reflect the wall performance under seismic loading. The energy dissipation before failure was also more reasonable for the shorter protocol.

(3) In all types of tests, 2.4 × 2.4 m shear walls sheathed with single oversize panel did not show a significant decrease in failure displacement, compared to walls with conventional sheathing, although an increase in strength and initial stiffness was observed.

(4) Dynamic tests suggest that stiff walls experience increased accelerations and decreased drifts, compared to more flexible walls. They were also found to have greater durability, considering the limited amount testing.

(5) A damaged 2.4 × 2.4 m shear walls constructed with a single oversize panel and reduced nail spacing can be retrofitted and still perform well in a significant earthquake.

(6) Major failure modes in all three types of tests were either nails pulling out of frame members or nails pulling through sheathing panels. No nail fatigue was observed in cyclic tests using the newly proposed test protocol and in dynamic tests using measured earthquake excitations.

(7) For shorter shear walls in which higher overturning moment existed, vertical dead load and hold downs played an important role to prevent the wall from uplift, which would decrease the lateral racking resistance.

REFERENCES

ASTM. 1991. *Standard Method of Static Load Test for Shear resistance of Framed Walls for Buildings.* ASTM E 564-76, ASTM, Philadelphia, Pa.

CSA. 1992. *Test Methods for Construction Sheathing.* CAN/CSA-O325.0-92, Canadian Std. Assc., Ottawa, ON.

Dolan, J.D. 1989. *The dynamic response of timber shear walls.* Ph.D. Thesis, Dept. of Civil Engrg, Univ. of BC, Vancouver, BC.

Durham, J. 1998. *Seismic Response of Shearwalls with Oversized Oriented Strand Board Panels.* M.A.Sc. Thesis, Dept. of Civil Engrg, Univ. of BC, Vancouver, BC.

Durham, J., Prion, H.G.L., Lam, F. and He, M. 1997. *Earthquake resistance of shearwalls with oversized sheathing panels.* Proc. Recent Advances in Understanding Full- Scale Behavior of Wood Buildings, Forest Prod. Soc., Madison, Wis., 57-64.

He, M., Lam, F., and Prion, H.G.L. 1998. *Influence of cyclic test protocols on performance of wood based shear walls.* Can. J. of Civil Engrg. NRC. Ottawa. 25, 539-550.

He, M., Magnusson, H., Lam, F., and Prion, H.G.L. 1999. *Cyclic performance of perforated wood shear walls with oversize OSB panels.* J. of Struct. Engrg. ASCE, Reston, Va., 125(1), 10-18.

Lam, F., Prion, H.G.L. and He, M. 1997. *Lateral resistance of wood shear walls with large sheathing panels.* J. of Struct. Engrg., ASCE, Reston, Va., 123(12), 1666-1673.

Latendresse, V. and Ventura, C.E. 1995. *Shake table testing of "ANTI-RAKKER™" device for plywood shear walls,* Research Report, Dept. of Civil Engrg, Univ. of BC, Vancouver, BC.