SMALL-SCALE RACK TESTING OF WOOD-FRAME SHEAR WALLS

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ABSTRACT

A series of racking tests were performed with small-scale (1.2-m × 1.2-m) plywood and OSB assemblies as a means of assessing the potential of reduced assembly sizes in screening variables for subsequent full-size tests. The plywood materials and configurations included variations in stud spacing, nailing, panel thickness and number, and addition of gypsum board. OSB assemblies differed in panel orientation and nailing. The framing used was KD Select Structural to minimize variations in fastening. Both of the standard assemblies (400-mm stud spacing) were also exposed to high relative humidity and effects of green framing. There were clear statistical differences between most plywood configurations, but the most prominent were for center-stud framing, and 9-mm-thick panels. The addition of gypsum board gave higher maximum load and greater stiffness, but the increased variability precluded finding significant differences with the basecase. OSB was significantly lower than plywood in most results. Moisture effects were minimal except for a greater deformation of OSB to the maximum load. The effect of green framing for the bottom plate was minimal.

Keywords: Racking, monotonic testing, oriented strandboard, plywood, seismic.

INTRODUCTION

A system was developed as a free-standing apparatus to test up to 1.2-m × 1.2-m wood-frame shear wall assemblies for seismic performance. Unfortunately, little work has been done on the performance of "small-scale" assemblies both in terms of sensitivity to variables and comparison to full-scale systems. The disadvantages of "full-scale" (2.4-m × 2.4-m assembly) testing are the combination of infrastructure, materials cost, materials characterization, testing time, and variation in results caused by materials variability. In addition, there is no assurance that a 2.4-m assembly is predictive of the response of an entire, nonperforated wall. Since two separate sheets of a 1.2-m × 2.4-m panel would normally be used in the full-scale assembly, there is no opportunity for replicate testing with subsections of a single panel.

The overall objective of this study was to determine if small assembly tests were sufficiently sensitive to changes in materials and properties to propose as a screening mechanism for subsequent full-scale tests. A wide range of panels smaller than a full sheet (1.2 m × 2.4 m) were tested, with the objective of finding the smallest assembly that gave a simulated seismic response to permit rapid screening of the many variables that could impact seismic performance.

BACKGROUND

Only a limited number of studies have been performed on assemblies smaller than 2.4 m × 2.4 m, and none was designed to determine if results from the smaller assemblies were scalable. In order to make the comparison, the assemblies would have to be constructed of replicate materials and fastened similarly, which has not been reported.

The conventional approach in simulated cyclic seismic testing is to run monotonic tests to obtain the load-deformation curve and from that curve obtain a reference deflection (Δ_r) that is used to establish a baseline deformation (Fig. 1). From the maximum load (P_{max}), the deformation at 0.8 P_{max} (deformation capacity, Δ_m) is obtained (the point of maximum deformation can also be determined by consensus). The reference deformation (Δ_r) is calculated as 0.6 Δ_m. Both factors (0.8 and 0.6) are completely arbitrary, being largely based on seismic testing of other materials, such as concrete.

Previous research

Langlois (2002) tested three 2.4-m × 2.4-m naked assemblies (those with only structural panels attached to the framing) monotonically to determine the load-displacement characteristics. For all three, the greater the initial stiffness (Ko), the lower the ductility (measured as the work to Δ_m); however, the displacements after P_{max} showed great variability, leading to Δ_m values with a CV of 24%. Since the variation in duc-

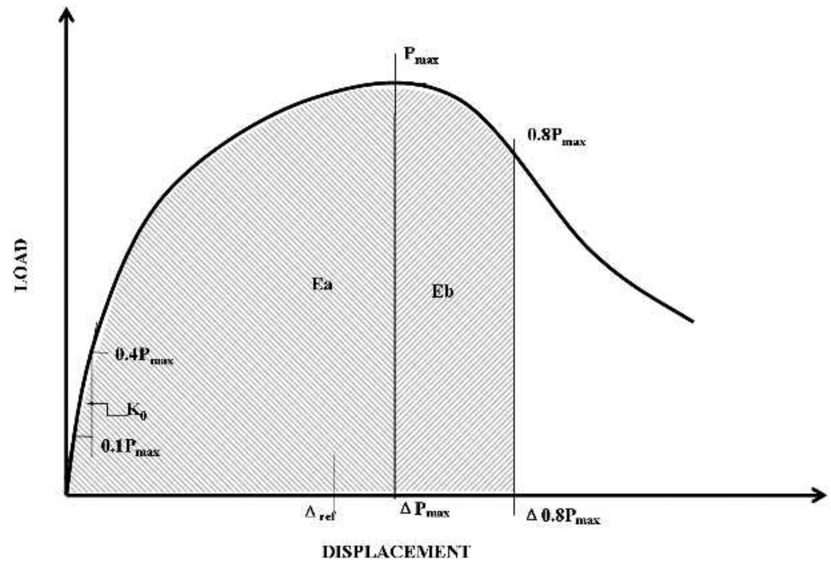

FIG. 1. Nominal diagram of monotonic racking curve and variables.

tility controlled the calculated Δ_r, he suggested that a different criterion be used to determine Δ_r. The CV of ΔP_{max} (12%) was about one-half that for energy dissipated, so he arbitrarily selected Δ_r as $0.8\Delta P_{max}$, which provided values that were essentially the same as the conventional Δ_r, although with one-half of the variability.

Testing of 1.2-m × 1.2-m assemblies has been previously reported (Hanson 1990) in a study done for the State Architects Office in California. The testing included 1.2-m × 1.2-m and 2.4-m × 2.4-m wall and diaphragm assemblies, using both 12-mm plywood (Structural-1 Douglas-fir) and OSB. The 1.2-m × 1.2-m assemblies were designed as a one-quarter scale of a typical 2.4-m × 2.4-m assembly by using two 0.6-m × 1.2-m panels with the seam at a center stud. The framing was Douglas-fir S&B 2×4 (moisture content was not given, but since this was done for California acceptance, the framing could have been green). Nails were 8d bright common with a nail spacing of 150 mm. The assembly was held in place with a 4-bar linkage (parallelogram) frame to prevent uplift, with the bottom plate torqued to 70 n-m. Four assemblies were tested, two each of plywood and OSB. The 1.2-m × 1.2-m wall assemblies were tested with load control according to Title 24 CA State Building Code (280 lb/lineal ft;100% = 1120 lb [5 kN]). The test cycles were 10 at +/- 75%, 100%, 150% design load, and 5 cycles at +/- 200%, 300%, all at 0.5 Hz. Apparently all of the assemblies survived testing. The wall displacements were about 10 mm for the 200% load (10 kN) and 25 mm in the first cycle for the 300% load (15 kN), with an increase of 25–35 mm in the subsequent 4 cycles. There was no appreciable difference between plywood and OSB behavior.

Zacher and Gray (1989) subjected woodframe assemblies of two sizes, 2.4 m × 2.4 m and 0.6 m × 0.6 m, in a series of dynamic tests. They found that the failure characteristics were similar between the two types of assemblies; however, no quantitative data were given.

The study of Salenikovich (2000) provides some data for assemblies narrower than 2.4 m. His naked, fully anchored assemblies (2.4 m × 2.4 m and 2.4 m × 1.2 m) had 0.6-m stud spacing and 150-mm edge nail spacing.

Lee and Hong (2000) conducted a rather interesting racking study on smaller scale models of shear walls. Their small-scale models were based on theoretical determinations of proportional dimensions of the elements that would produce ¼-scale values of ultimate loads. These reductions were size of framing (18 mm × 43.5 mm vs. 38 mm × 89 mm), thickness of plywood (4.8 mm vs. 11.1 mm), and stud spacing (200 mm vs. 400 mm) for the simplest assemblies (0.6 m × 1.2 m vs. 1.2 m × 2.4 m). Preliminary tests were run on three nail sizes and two plywood thicknesses to obtain the desired results for scaling. Three tests were run on the full-size and two on the small-scale assemblies. Based on the data presented (with no statistical information), multiplying the small scale P_{max} by 4 gave 96% of the full-scale value. Deformation of the small-scale assemblies was similar to about one-half the ultimate load, but then increased considerably with load beyond that point. For example, at 1.7% drift, the small-scale assembly was at 78% of the full-scale load (using the multiplier of four). While this study was interesting, it involved questionable scaling methods of sizes of fasteners and plywood to permit a fit with the proposed theoretical relationships.

Serrette et al. (1997) tested several configurations of 2.4-m × 2.4-m assemblies including plywood and OSB sheathing, combined plywood and gypsum board, vertical and horizontal panel orientations, and with screw and nail fasteners. Companion small-scale tests were made with 610-mm × 610-mm sandwich sections having fasteners with 150-mm spacing. These tests were designed for testing the shear behavior along the edge of panels, and not to simulate the rotation associated with panel to framing connections during racking.

Preliminary small panel testing

Several assemblies having panels smaller than a full sheet (1.2 m × 2.4 m) were tested, with the objective of finding the smallest assembly size that gave a simulated seismic response that could permit rapid screening of the many variables that could impact seismic performance. The initial test assembly width was based on the smallest stud spacing in commercial practice (0.4 m), and the height was selected as 0.6 m to maintain a suggested 1:1.5 aspect ratio. The next logical width increment is 0.6 m, consistent with the other stud spacing in practice, and a height of 0.9 m. For these two sizes, it was possible to obtain 12 and 4 specimens from each full-size panel, respectively. These tests also provided an opportunity to test and fine-tune the actuator system, instrumentation, frame construction, and holddowns, including corner braces. When the analysis was completed, we recognized that despite the advantages of being able to test a number of replicates from each panel, there were some distinct disadvantages:

- Stud spacing. Neither of these sizes permitted the testing of both stud spacings (0.4 m and 0.6 m) with the same panel size.
- Nail spacing. For the small assembly sizes, it was difficult to obtain nail spacing that complied with commercial practice.
- Out-of-plane flexure. During testing, it was obvious that flexure occurs in the panels in both the vertical and horizontal axes from the "ride-up" of the corners of panels on the bent nails. There was approximate symmetry about the centerlines in the two directions where little if any deformation occurred. However, because of the short width for both panel sizes, it meant that the panels had a much stiffer behavior than a full-size 1.2-m-wide sheet.
- Gypsum board behavior. These boards are manufactured with densified edges. If we were to use less than a 1.2-m × 1.2-m section of gypsum board, then there would be fewer densified edges, which could bias the nailing integrity.
- Panel alignment. Horizontal or vertical alignment of panels substantially changes the elastic and plastic behavior. For panels with an aspect ratio other than 1:1, it is not possible to obtain matched specimens from the same full-size sheet.
- Void and density distribution. As panels are reduced in size, the potential impact of voids and areas of high and low density is increased.

Based on the behavior of these smaller panels and the issues above, we elected to use 1.2-m × 1.2-m assemblies. It also gave us the ability to use the same frame assembly for both (0.6 m, 0.4 m) field stud spacings, more uniformity in nail spacing (75 mm, 100 mm, 150 mm), and not overly compromise the attachment of gypsum board (with densified edges). In addition, the scale effects of holddown, out-of-plane deformation, and variation of materials properties would be very similar to the full-size panels. Out-of-plane deformation, which is a maximum at the panel corners, causes pull-out of nails. This was considered especially important, since it would affect nail withdrawal in our planned green framing tests. While this size reduced the replicates to 2 per full-size panel, it satisfied the desirability to have matched tests from the same full-size sheet, and end-matched, which would be less variable than side-matched. It also permits testing of horizontal vs. vertical flake alignment for OSB with the same assembly configuration.

EXPERIMENTAL PROCEDURE

Experimental variables

Basecases.—There were two base cases for the 1.2-m × 1.2-m tests:

- PW(S): S = standard; nominal 12-mm Structural-1 Douglas-fir plywood (actual thickness: 11.5 mm)
- OSB(S): S = standard; nominal 12-mm Exposure-1 sheathing grade (actual thickness: 12.5 mm)

Each of the basecases had 400-mm stud separation, 150-mm edge nail (8d coated), and 300-mm field nail (8d coated) spacing. The framing material was 2×4 KD Douglas-fir Select Structural grade to minimize interference from defects and moisture content changes. Single framing members were used for all edges. Framing nails were 16d bright.

Material and configuration changes.—For the plywood assemblies, there were four configurations beyond the standard:

- PW(C): Field stud in the center only
- PW(CFN): Close field nailing (150 mm) with the standard framing configuration
- PW(H): "Hansen" configuration (two 1.2-m × 2.4-m panels with a center stud)
- PW(9): 9-mm plywood with the standard framing configuration

The OSB assemblies included two configurations beyond the standard:

- OSB(CCN): Close corner nailing (two additional nails at each corner for 75-mm spacing)
- OSB(HO): Horizontal orientation of panels
- *Moisture content effects.*—PW(RH) and OSB(RH): High humidity (85%) exposure for a 6-wk period followed by immediate testing. A matched set of OSB was also sprayed every 3 d with 1 L of water over a 6-wk period, and permitted to equilibrate at 18% EMC to simulate wetting from condensation/wetting in service.
- PW(T) and OSB(T): Preservatively treated bottom plate nailed in "wet" condition, permitted to dry, and tested at ambient conditions

Equipment

The assemblies were tested using an MTS 407 controller with a 25-kN actuator mounted on a 0.9-m × 3.6-m 10-t table (Fig. 2). The test system was designed to be self-reacting since the floor at the Forest Products Laboratory was in-

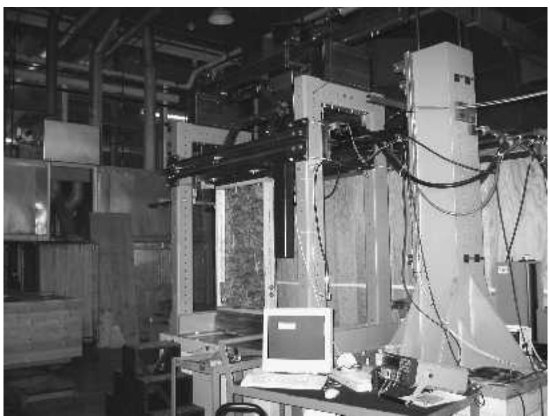

FIG. 2. Monotonic racking system with MTS controller and actuator.

adequately reinforced. The actuator drives an upper loading head that is stabilized laterally with guide rollers, and has a special fixture that permits horizontal and vertical movement, but prevents rotation in the plane of the assembly. The system is programmed for both monotonic and dynamic testing, and for automatic data acquisition. The monotonic test assemblies were racked at a constant rate of 0.5 mm/s, which is typical for wood shear walls. For all tests, there were four replications.

Test alterations

From information learned in preliminary tests, there were several measures taken to assure consistent results:

- Plate extensions. The top and bottom plates were lengthened to provide 100-mm extensions beyond the vertical end studs to minimize splitting at the corners.
- Nailing fixture. A table was constructed with templates to assure the proper placement of studs and nailing of both framing and panels.
- Testing endpoint. After some of the initial tests, the load was released when reaching 0.8 P_{max} (beyond P_{max}) to provide better visual information on nail performance at the conclusion of racking. Continuation beyond this point has no value is assessing performance.

The results from over 50 preliminary tests provided substantial evidence that the focus of the research should be on (1) the behavior of fasteners at the assembly corners, where out-of-plane deformation of the panels occurs, (2) the flexural properties of the fasteners, (3) factors that affect fastener withdrawal, such as nail type, green framing effects, and panel integrity, and (4) the relationship of panel swelling, MC, and local density (near fasteners).

RESULTS AND DISCUSSION

Tables 1 and 2 show the data collected on monotonic testing. Each table uses plywood and OSB panel assemblies with the "standard configurations" for reference. Tables 1a and 1b describe results for the effects of varying the materials and assemblies; Tables 2a and 2b are for moisture effects on the standard configurations.

TABLE 1A. *Material and configuration effects for monotonic testing of 1.2-m × 1.2-m assemblies (% CV in parentheses).*

	Max load (kN)	Deflection max load (mm)	Deflection 0.8 max load (mm)	Initial stiffness[a] (MN/m)	Stiffness ratio PW(S) = 1
PW(S)	*18.3(5)*	*46(8)*	*88(6)*	*2.69(30)*	*1.00*
PW(C)	15.5(6)***	44(17)	80(15)	1.87(26)*	0.70
PW(H)	17.8(3)	62(6)***	117(3)***	2.26(13)	0.84
PW(CFN)	17.6(4)	51(10)	102(9)*	2.27(5)	0.84
PW(9)	13.1(2)***	34(6)***	73(10)***	1.64(20)*	0.61
PW(G)	19.3(10)	38(14)*	74(5)***	3.29(8)	1.22
OSB(S)	14.8(3)***	44(5)	83(4)	1.26(7)**	0.47
OSB(S)	*14.8(3)*	*44(5)*	*83(4)*	*1.26(7)*	*0.47*
OSB(CCN)	17.3(3)***	39(11)	77(5)	2.40(6)***	0.89
OSB(HO)	15.5(7)	43(12)	778(6)	2.14(27)*	0.80

S = Standard assembly
C = 0.8-m field stud spacing
H = Hansen (1990) configuration
CFN = Close-field nail spacing
9 = Panel thickness (mm)
G = Gypsum board added
CCN = Close-corner nail spacing
HO = Horizontal orientation of panel
[a] Slope to 0.4 max load
* Significant at 90% level
** Significant at 95% level
*** Significant at 99% level

TABLE 1B. *Energy dissipation for materials and configurations in monotonic testing of 1.2-m × 1.2-m assemblies (%CV in parentheses).*

	Energy dissipation (kJ) by applied force				Energy dissipation (kJ) by displacement	
	Partial to Pmax	Partial, Pmax to 0.8 Pmax[a]	Total to 0.8 Pmax[a]	Partial ratios	0–12 mm	0–24 mm
PW(S)	*0.675(11)*	*0.713(13)*	*1.39(8)*	*1.1*	*120(11)*	*259(9)*
PW(C)	0.538(23)*	0.520(28)**	1.06(19)**	1.0	95(11)**	244(9)***
PW(H)	0.893(4)***	0.907(7)**	1.80(3)***	1.0	107(9)	266(6)
PW(CFN)	0.732(17)	0.836(23)	1.57(5)*	1.2	110(7)	280(6)
PW(9)	0.363(17)***	0.480(24)**	0.84(13)***	1.3	94(5)**	241(2)**
PW(G)	0.615(20)	0.638(10)	1.25(8)	1.0	140(4)**	348(4)**
OSB(S)	0.494(3)***	0.572(6)*	1.07(2)***	1.2	98(4)**	241(1)**
OSB(S)	*0.494(3)*	*0.572(6)*	*1.07(2)*	*1.2*	*98(4)*	*241(1)*
OSB(CCN)	0.521(14)	0.630(9)	1.15(9)	1.2	117(8)**	297(7)***
OSB(HO)	0.556(22)	0.604(30)	1.16(12)	1.1	109(10)	271(8)*

S = Standard assembly
C = 0.8-m field stud spacing
H = Hansen (1990) configuration
CFN = Close-field nail spacing
9 = Panel thickness (mm)
G = Gypsum board added
CCN = Close-corner nail spacing
HO = Horizontal orientation of panel
[a] Slope to 0.4 max load
* Significant at 90% level
** Significant at 95% level
*** Significant at 99% level

TABLE 2A. *Moisture effects for monotonic testing of 1.2-m × 1.2-m assemblies (% CV in parentheses).*

	Max load (kN)	Deflection max load (mm)	Deflection 0.8 max load (mm)	Initial stiffness[a] (MN/m)	Stiffness ratio PW(S) = 1
PW(S)	*18.3(5)*	*46(8)*	*88(6)*	*2.69(30)*	*1.00*
PW(RH)	19.7(11)	58(16)*	81(8)	1.89(27)	0.70
OSB(S)	*14.8(3)*	*44(5)*	*83(4)*	*1.26(7)*	*0.47*
OSB(RH)	14.8(3)	52(4)***	74(11)*	1.32(21)	0.49
PW(S)	*18.3(5)*	*46(8)*	*88(6)*	*2.69(30)*	*1.00*
PW(T)	17.1(5)	51(7)*	84(5)	1.67(15)*	0.62
OSB(S)	*14.8(3)*	*44(5)*	*83(4)*	*1.26(7)*	*0.47*
OSB(T)	14.6(4)	40(10)	80(5)	1.44(3)**	0.54

S = Standard assembly
RH = Aged at 85% RH
T = Treated bottom plate nailed "green," dried to ~12% MC
[a] Slope to 0.4 max load
* Significant at 90% level
** Significant at 95% level
*** Significant at 99% level

By convention, the initial stiffness (Ko) is taken as a linear segment from 0 to 0.4 P_{max}. However, the data at the origin were not sufficiently reliable, and therefore Ko was determined from 0.1 to 0.4 P_{max}. Tables 1b and 2b show energy dissipation for all of the tests. There are several ways to determine energy dissipation, one based on load limits (P_{max} and 0.8 P_{max}) and another on energy consumption for a specific drift or displacement. The energy absorbed by the system based on load application can be obtained by the area under the load-displacement curve:

TABLE 2B. *Energy dissipation for moisture effects in monotonic testing of 1.2-m × 1.2-m assemblies (%CV in parentheses).*

	Energy dissipation (kJ) by applied force				Energy dissipation (kJ) by displacement	
	Partial to Pmax	Partial, Pmax to 0.8 Pmax[a]	Total to 0.8 Pmax[a]	Partial ratios	0–12 mm	0–24 mm
PW(S)	*0.675(11)*	*0.713(13)*	*1.39(8)*	*1.1*	*120(11)*	*295(9)*
PW(RH)	0.871(27)	0.412(18)***	1.28(18)	0.5***	99(1)*	254(10)*
OSB(S)	*0.494(3)*	*0.572(6)*	*1.07(2)*	*1.2*	*98(4)*	*241(1)*
OSB(RH)	0.635(3)***	0.284(27)***	0.92(14)	0.4***	93(6)	230(4)
PW(S)	*0.675(11)*	*0.713(13)*	*1.39(8)*	*1.1*	*120(11)*	*295(9)*
PW(T)	0.662(10)	0.538(12)**	1.20(9)*	0.8*	96(7)**	250(7)**
OSB(S)	*0.494(3)*	*0.572(6)*	*1.07(2)*	*1.2*	*98(4)*	*241(1)*
OSB(T)	0.458(13)	0.533(7)	0.99(4)**	1.2	89(4)**	234(5)

S = Standard assembly
RH = Aged at 85% RH
T = Treated bottom plate nailed "green," dried to ~12% MC
[a] 0.8 Pmax is *after* Pmax
* Significant at 90% level
** Significant at 90% level
*** Significant at 90% level

- Ea: the energy to P_{max}, the region of increasing resistance to deformation.
- Eb: the post-peak energy between P_{max} and 0.8 P_{max}. In this region, the assembly responds to increasing deformation with greater damage and decreasing load resistance.

Also, the energy based on displacement was selected for 1% (E_{12}) and 2% (E_{24}) drift (1% drift = 12 mm).

The data were analyzed for statistical correlation of results for each test relative to the "standard configuration (either PW(S) or OSB(S)). The variability observed in these tests was considerably lower than observed for full-scale testing, where statistical relationships are typically not reported.

In order to summarize the data of test groups, a regression was run for each group of curves to provide an "average" curve to represent the group. This was thought to be more meaningful than selecting a "typical" result. For example, Fig. 3 shows the individual runs for PW(S), the curve-fitted value, and the 15% confidence limit, which is similar to the overall variance of the replicates. Figure 4 gives the results in terms of the average curves for the two standard assemblies and their confidence intervals.

Effects of assembly variables

Figures 5 and 6 show the fitted curve data for the plywood and OSB tests that had variations in the assemblies and/or materials. Table 1a gives the load-deflection results for these tests. One of the most important variables from monotonic testing is P_{max}. PW(G) had the highest average P_{max}, but also had the highest variability, and therefore was NS with respect to PW(S). The plywood assemblies that were significantly different (at various levels) with respect to PW(S) included PW(C), which was about 15% lower, and PW(9), 29% lower.

When a center stud was used, PW(C), the results were very similar to OSB(S) although for a different reason. The center stud rotates with the panel with little effect on the fasteners, and does not contribute to the properties of the assembly. Typically, as the frame assembly deforms from a square to a rhombus, the panel rotates about the centerlines vertically and horizontally, with the maximum displacements occurring at the four corners. The PW(9) was tested to understand the sensitivity of the assembly to panel characteristics. The results show that P_{max} and Δ_{pmax} were about 0.73 of the P(S), but the energy dissipation was even lower (0.56). As a rough approximation, the square of the thickness ratio of the two plywoods was 0.62 compared with 0.61 for the

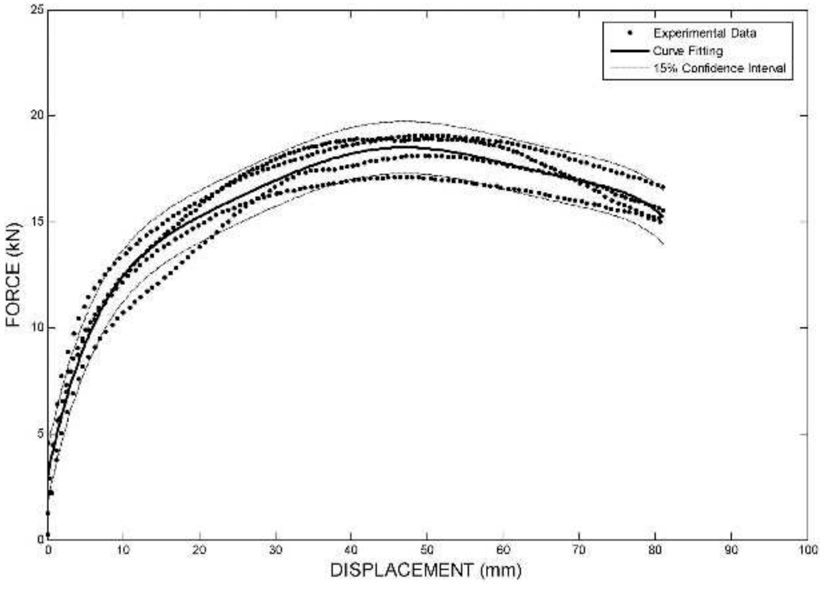

FIG. 3. Use of curve-fitting to develop an "average" curve for the standard plywood configuration.

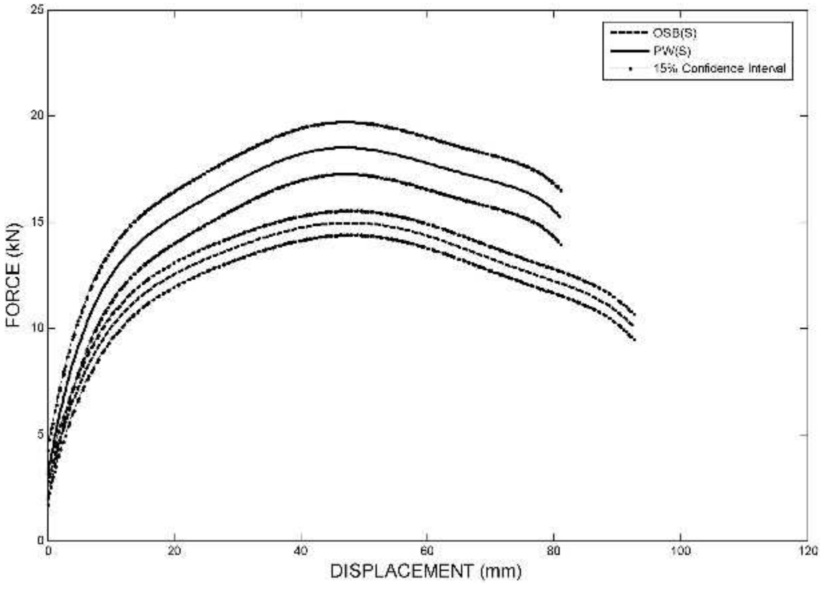

FIG. 4. Average curves (from curve-fitting) for PW(S) and OSB(S) showing 15% confidence intervals.

initial stiffness ratio. The standard assemblies were also modified with close-field nailing of the two field studs (150 vs. 300 mm) as shown by PW(CFN), but the effects were not significantly different from PW(S). The "Hanson" configuration was tested to see how different it might be, since the two smaller panel sections (1.2 m × 0.6 m) would rotate independently on the center stud. In comparison with PW(C), PW(H) was stiffer (21%) and had a 14% higher P_{max}. This was expected, since the smaller panels would be stiffer than a 1.2-m × 1.2-m panel, and demon-

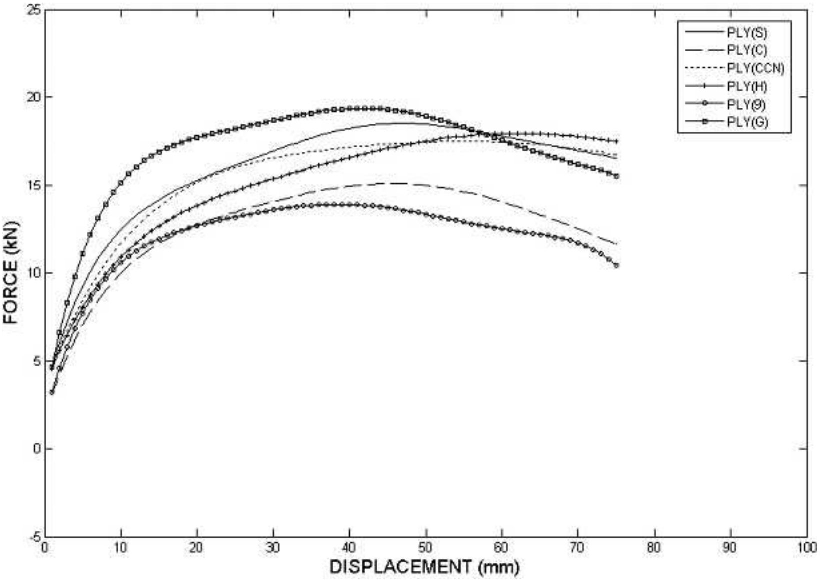

FIG. 5. Average curves for plywood assemblies with different materials and configurations.

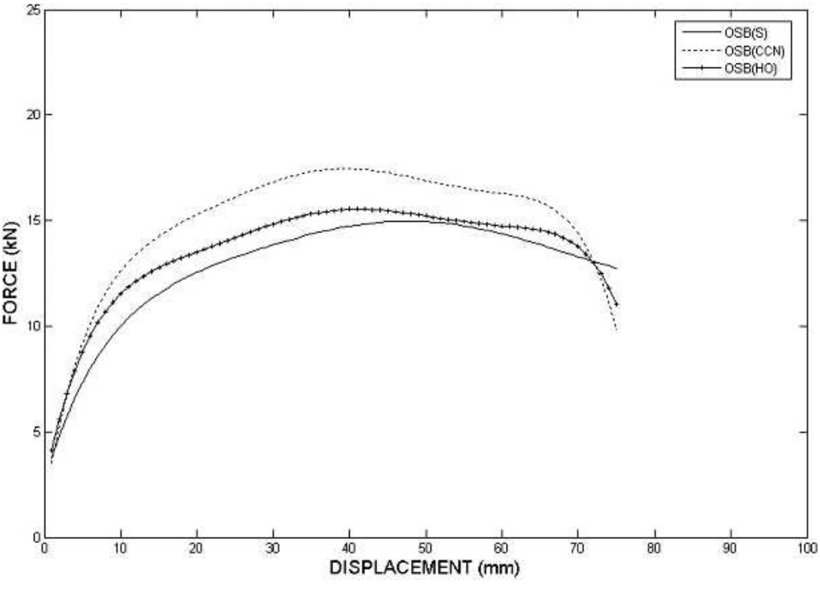

FIG. 6. Average curves for OSB assemblies with different configurations.

strates the contribution of panel stiffness to the racking performance. This also verified that panels smaller than 1.2 m could bias the racking performance. The largest difference in PW(H) was the excessive deformation to P_{max} and 0.8 P_{max}, undoubtedly caused by the ability of both panels to rotate. The PW(H) configuration has an interesting contrast with higher stiffness (from the smaller panels) and yet greater deformation (from the panel rotations).

Initial stiffness values for the plywood assemblies had a wide range of average values (1.64 to

3.29), but only the two lowest values (PW(C) and PW(9)) had any significant correlations because of the variability. This variability is not surprising since there was no indication of linearity in this portion of the plots. However, it is interesting that there is a reasonable correlation between average values of Ko vs. P_{max}, although the highest P_{max} values have disproportionally higher stiffnesses (Fig. 7). The stiffness of OSB(S) was considerably lower than would be expected from the plywood relationships, although the other two OSB assemblies followed the plywood trend line. In contrast, PW(9) had a lower than predicted P_{max} from the relationship.

OSB(S) was significantly lower in P_{max} (about 20%) than PW(S) and was also lower than the OSB(CCN). The lower value of OSB relative to plywood appeared to have been caused by the greater nail tear-out at the OSB corners. The close-corner nailing of OSB also raised the value of P_{max} for that assembly to an intermediate value between PW(S) and PW(C). The deflection to the maximum load was less for OSB than plywood (but not statistically different). Deflection of the assemblies in racking is a very important characteristic in that too much deflection leads to greater loss of fastener integrity, while too little tends to concentrate the force in the panel where shear failure can occur. The other differences were the initial stiffness (0.69), and energy dissipated (0.76), which are interrelated because of the slope of the initial deformation.

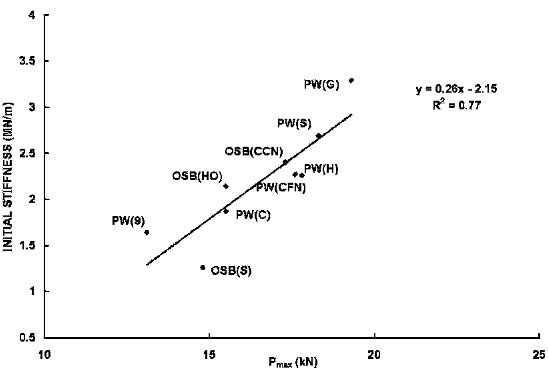

FIG. 7. Relationship of initial stiffness (see Fig 1) to P_{max}.

There were two assembly variations for OSB (Fig. 6). In the "close-corner" nailing, OSB-(CCN), two nails were added at each corner for 75-mm spacing. This was done to see if the added stiffness would be adequate to reduce nail tear-out or pull-out at these extreme points. Relative to OSB(S), Ko was substantially higher at 1.58 and P_{max} was also higher (1.17), although the total energy was only slightly greater. It is interesting that OSB(CCN) had similar stiffness and P_{max} as PW(S), although the deformation capacity was slightly lower (0.93). The values for OSB(HO) were not significantly different from OSB(S).

Of the plywood tests, PW(S) had higher total energy dissipation than PW(C) and PW(9), and lower than PW(H) and PW(CFN). At both 12 mm and 24 mm, PW(C) and PW(9) were also lower, but PW(G) had significantly greater displacement energy and did differ in load-related energy. The ratio of partial to total energy dissipation was of interest because it reflects the ability of the assembly to absorb more energy under load degradation after P_{max}. The largest ratio was for PW(9) even though the total energy was the lowest of the five configurations, about 60% of that of PW(S). PW(CFN), which had a lower stiffness than PW(S), nevertheless was 13% higher in total energy and only marginally lower than PW(S) to 12 mm. PW(C) was 24% lower in total energy and 21% lower than PW(S). The three OSB configurations had about the same total energy dissipation even with widely differing load and displacement values (Table 1b). OSB(CCN) had a significantly greater displacement energy dissipation to both 12 and 24 mm. Figure 8 shows the relationship of initial stiffness to total energy dissipation. Langlois (2002) found an inverse relationship of these variables, implying that greater stiffness would lead to more damage, limiting the energy dissipation. However, our results showed no relationship of these variables.

Although there are few literature sources from which to make comparisons, the results of Salenikovich (2000) are useful to analyze with respect to OSB performance, despite possible influences from density and moisture content. In

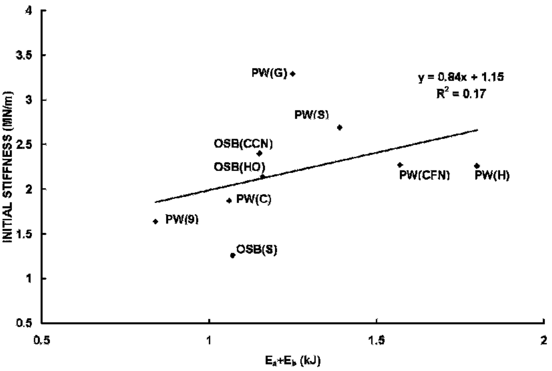

FIG. 8. Relationship of initial stiffness (see Fig 1) to energy dissipation.

the data below, two values are given for 1.2-m × 1.2-m assemblies, the first from Table 1a, and the second using an adjustment for panel thickness based on data in this paper relating the corresponding values for PW(S) and PW(9). With those caveats, the maximum loads and initial stiffnesses for the data were:

Assembly	Max load (kN)	Initial stiffness (MN/m)
2.4 × 2.4 m (Salenikovich)	24.3	1.8
2.4 × 1.2 m (Salenikovich)	10.6	0.7
1.2 × 1.2 m (Beall et al.)	14.8	1.26
[1.2 × 1.2 m (Beall et al.)	13.0*	0.97**]

The values marked (*) are adjusted for panel thickness, based on the thickness ratio for P_{max} (*) and square of thickness for Ko (**). In comparing the above 1.2-m × 1.2-m values with the Salenikovich 2.4-m × 2.4-m, it is interesting that both the adjusted P_{max} and stiffness are about 50% of these values. Both 1.2-m × 1.2-m values are considerably greater than that for the 1.2 m × 2.4 m, which would be expected. In the current study, OSB(S) was about 81% of the P_{max} of PW(S); however, if we apply the same thickness adjustment, it would lower OSB(S) to 74% of PW(S).

Some full-scale (2.4-m × 2.4-m) tests conducted by Serrette et al (1997) were useful for comparison to our results. For example, nailed plywood and OSB had similar ultimate loads in contrast with the 80% lower value for OSB in our studies. Horizontal (blocked) and vertical orientation of OSB had similar greater values (about 5%) in each study, although these were not significant. The gypsum and plywood combination in Serrette was about 23% greater than plywood, in comparison to the 6% (but not significant) difference in this study.

Moisture effects

After moisture conditioning at 85% RH for 6 wk, the plywood and OSB panels were 19% and 17% MC, respectively, and the framing averaged 20% MC. When analyzed, it was found that the matched sets with intermittent water spray, which reached the same equilibrium conditions, had no significant effect on the results. This could be because of the open cavity and/or quantity of water, but further testing is needed to propose a method of exposure that reasonably represents the effect or range of possible effects of moisture in a wall cavity. The results of these effects are shown in Fig. 9. For all of the high RH exposures, the deformation capacity increased (1.17) and Ko decreased (0.92); however, the major effect was the reduction in energy dissipated (0.87) and energy ratio (about 0.45). The ratio was lower because of the increased deformation capacity, which included a substantially greater (1.26) fraction up to P_{max}, as a result of much greater tear-out of nails in the high RH panel material.

At this point, it is uncertain if the differences from high RH were as a consequence of "softening" of the OSB or greater nail withdrawal from the higher MC framing, so a matched set of plywood assemblies were also exposed to high RH, PW(RH). In this case, the major differences were a decrease in Ko (0.83; which was greater than the relative change of OSB), and a much greater ΔP_{max} (1.26), but with a lower energy dissipation (0.92). The major observed difference between the assemblies was that the fasteners tended to pull out of the framing with PW(RH), while they tore out of the panels with OSB(RH).

Since it was not possible to separate the effects of elevated moisture content of the panels

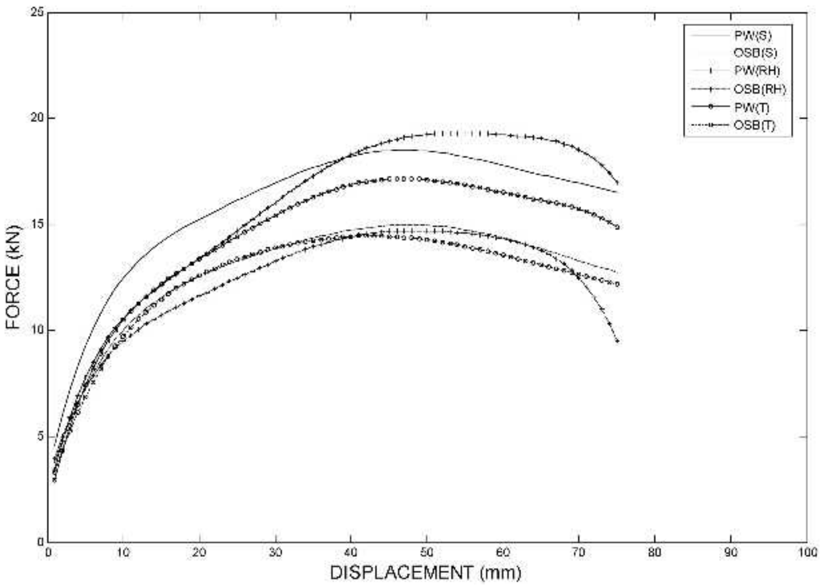

FIG. 9. Average curves for moisture testing on standard plywood and OSB assemblies.

and frames, tests were performed using bottom plates that were at high moisture content when nailed. This was done by using preservatively treated plates, nailed "green" and permitted to dry to about 12% MC in the laboratory (designated PW(T) and OSB(T). The expectation was that both plywood and OSB would have some reduced values; however, the results were somewhat puzzling. In general, the plywood values were lower for the treated plates and OSB higher, relative to the standard assemblies for each type. This was particularly noticeable for Ko (0.8 for PW(T) and 1.23 for OSB(T)). One effect that is especially puzzling is the substantial relative reduction in energy dissipation for PW(T) after P_{max} (0.8 vs. 1.1 energy ratio). The results raise questions about the appropriateness of using the recommended reduction in nail withdrawal values for racking exposure.

Monotonic vs. cyclical testing

The monotonic tests were initially performed to obtain a reference deformation and then conduct dynamic tests using the ordinary-field CUREE protocol. The displacement at 0.8 P_{max} has been selected by some researchers as the deformation capacity and the point for calculating the reference displacement (0.6 of 0.8P_{max}). This reference displacement is then used to determine the baseline displacement in cyclical tests. Unfortunately, the variability caused by cumulative damage among the tests makes this reference value arbitrary. In many cases, the reference deformation is greater than the P_{max} displacement, meaning that the baseline displacement can be within an area of substantial damage accumulation, at least for some assemblies. As an example, all of the assemblies in Table 1a would have reference values that exceed the deformation at P_{max}. In addressing the problem with CUREE testing of 2.4-m × 2.4-m walls, Langlois (2002) selected a reference value of 0.8 of the deformation capacity, which was more repeatable since it was not dependent on the much greater variability caused by damage after P_{max}. Because of the issue of choosing an adequate (and defensible) reference value, we deferred the CUREE tests and will use tests in the future where such a reference value is not required, or if required, will consider the criterion of Langlois.

CONCLUSIONS

The small scale (1.2-m × 1.2-m) racking system provided good sensitivity to variations in materials, assemblies, and moisture exposure. It permits rapid and relatively low-cost means of screening the effect of variables for subsequent full-scale tests. With the caveat of the use of the particular materials, the tests showed the following:

1. With a Structural-1 plywood panel and 400-mm stud spacing as a base case, there were statistical differences with load-deflection and/or energy dissipation of the following plywood assemblies: center stud, "Hansen" configuration, 9-mm plywood panel, and addition of gypsum board. Close-field nailing (150 mm) did not affect the results.
2. Comparable assemblies with OSB were significantly lower than the plywood basecase in maximum load, initial stiffness, and energy dissipation. The coefficient of variation of OSB assemblies was about one-half of that of plywood.
3. With an Exterior 1 sheathing grade OSB panel and 400-mm stud spacing as a base case, there were statistical differences with load-deflection and/or energy dissipation of assemblies with close-corner nailing (two additional nails per corner), but minor differences with horizontally oriented panels. The addition of the close-corner nailing raised the test values to the level of the plywood panel basecase.
4. The effect of high humidity exposure was minimal for the standard plywood assembly, with the exception of a substantially lower energy dissipation after the maximum load. However, OSB showed an increase in deflection to the maximum load and consequently greater energy dissipation to this point. An attempt to use water spray in the open cavities did not produce significant differences from the high relative humidity exposure, perhaps as a result of an inadequate exposure protocol.
5. Tests done with treated wood bottom plates, nailed "green" and dried before testing, showed few differences, and raised questions about the appropriateness of lower nail withdrawal recommendations for green framing.

The next major need in this research is to fabricate 1.2-m × 1.2-m and 2.4-m × 2.4-m assemblies using matched materials to determine if the small-scale system is an adequate predictor of full-scale behavior. We also need local data on panel and frame density to better understand the variation in fastener behavior.

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