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COMPARISON OF THE STRUCTURAL CAPACITY OF SHEAR WALLS SHEATHED WITH ORIENTED STRAND BOARD AND CELLULOSIC FIBER BOARD SUBJECTED TO CYCLIC LOADING

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ABSTRACT: Eight wood framed shear walls were subjected to the ASTM E2126-11 cyclic testing protocol at 0.5 Hz. Four 2.44 m x 3.66 m shear walls were sheathed with 12 mm (15/32") thick oriented strand board (OSB), oriented vertically and connected to the frame with 60 mm x 2.9 mm (2 3/8" x 0.113") nails spaced at 150 mm along all edges. Four walls were sheathed with 3.43 mm thick Cellulosic fiber board (CFB) sheathing connected to the frame with 16-gauge, 23.8 mm (15/16") crown staples spaced 75 mm on center along the perimeter and in the field. The TPB sheathing is comprised of 94% post-consumer recycled materials.

Hysteresis results show that both the OSB and CFB walls exhibited typical wood frame shear wall behavior, characterized by elliptical hysteresis with pinched behavior at low levels of displacement. For cycles 1 through 31 (displacements less than 25 mm), the percent difference in average load capacity from the CFB and OSB walls ranged from +10% to -1.2%. At large displacements (greater than 45 mm) the CFB walls exhibited less capacity than the CFB walls. The OSB average maximum load is 25.9 kN and occurs at a wall displacement of 61 mm (cycle 35), while the CFB average maximum load is 24.1 kN at a displacement of 43 mm (cycle 32).

KEYWORDS: wood shear wall, sustainable sheathing, recycled sheathing, load capacity, cyclic testing

1 INTRODUCTION

Plywood and oriented strand board (OSB) have traditionally been the most common and effective sheathing used on wood shear walls to provide strength against lateral loads. Drawbacks to utilizing traditional sheathing include construction time, moisture absorption, and in recent years, wildly fluctuating prices. Cellulosic fiber board (CFB) serves as an alternative to traditional sheathing. Construction utilizing CFB can be more efficient (time and effort); it can be moisture and mold resistant; and it is largely made from post-consumer material making its prices more stable. It is critical that the strength of these materials be understood for use in wood shear walls subjected to lateral loading.

2 BACKGROUND

Seismic and wind forces acting on wood structures are generally carried by wood framed shear walls. Until the mid 1980's shear walls were sheathed with plywood. At this time the use of oriented strand board gained in popularity and acceptance for lateral force resistance. [1] Research demonstrated that shear walls sheathed with comparable thicknesses of plywood and OSB performed similarly under static and cyclic lateral loading. Load capacity, walls stiffness, energy dissipation and failure modes were nearly identical. [2, 3]

While the construction industry continues to investigate sustainable, green, and recycled materials, CFB has not gained the same widespread acceptance as OSB. This may be in part due to the strength of CFB not being well understood. A review of the strength and stiffness of oriented wood and cellulose-fiber materials that indicates the strength potential inherent to biobased cellulosic materials has been conducted to ascertain their suitability for potential applications.[4] Each type of material was described in terms of structure and corresponding representative values for strength and modulus of elasticity in fiber direction.[4]

Structural sheathing products utilizing CFB can be made from recycled material, are much thinner than comparable OSB panels, and are connected to the wall framing via staples. Proprietary information regarding the strength of these products is shared with manufacturers; however,

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there has been little published data available. The structural sheathing utilized in this study is made from 94% post-consumer recycled materials and is marketed as Thermo-Ply®.[5]

3 SHEAR WALL TEST SPECIMENS

Eight, 2.44 m tall x 3.66 m long (8' x 12') shear walls were supplied by Ox Engineered Products, LLC. All studs and plates consisted of 2x4 SPF No. 2 lumber, with studs spaced at 406 mm (16") on center, continuous bottom and top plates, top plates fastened with 76.2 mm x 3.33 mm (3" x 0.131") nails at 610 mm (24") on center, staggered from each side. Studs were fastened to the plates with two 76.2 mm x 3.33 mm (3" x 0.131") toenails. Double end studs (each end) were fastened with 76.2 mm x 3.33 mm (3" x 0.131") nails at 609.6 mm (24") on center from each side.

Four walls were sheathed with OSB, oriented vertically, and connected to the frame with two 9.53 mm x 2.87 mm (3/8" x 0.113") nails spaced at 152 mm (6 inches) along all edges. Four walls were sheathed with CFB oriented vertically and connected to the frame with 16 gage, 23.81 mm (15/16") crown staples [minimum penetration of 25.4 mm (1") into the stud] with the crown parallel to the framing and spaced 76.2 mm (3") on center along the perimeter and in the field. The staple head was in contact with the CFB surface. The edge distance for all fasteners was 9.53 mm (3/8") and sheathing panel joints were butted. Figure 1 shows a completed CFB wall. The CFB used in this study was ThermoPly Blue.

Figure 1: *CFB Shear Wall Test Specimen*

4 EXPERIMENTAL TEST SETUP

4.1 TEST FRAME AND LOADING MECHANISM

The test frame consists of a frame base, actuator, load spreader device, and lateral restraints. An elevation of the framing plan is exhibited in Figure 2. Three W8x24 beams in series formed the frame base of the system. The beams were anchored to the concrete floor to ensure no slippage of the frame during the test. A 38.1 mm thick by 88.9 mm wide (1 ½" x 3 ½") plate was welded to the top flange of each beam, allowing for sheathing rotation and deformation without interference by the beam flange.

Threaded holes, 22.23 mm (⅞") in diameter, were drilled every 203 mm (8 inches) into the plate to accommodate the different anchorage patterns needed for the various wall configurations. Two 3.66 m 50.8 mm x 101.6 mm (12'-0" 2"x4") pieces of #2 Hem Fir were placed atop the welded plate, anchored to the beams using four 19.05 mm (¾") diameter hex bolts, and tightened down in countersunk holes to be flush with the wood surface. Two additional 19.05 mm (¾") holes were drilled, one at either end of the planks and in line with the existing holes of the welded plate, to accommodate the 15.88 mm (⅝") anchor bolts of the 10-gauge Simpson Strong-Tie HD5B hold-down anchors at the corners of the shear walls.

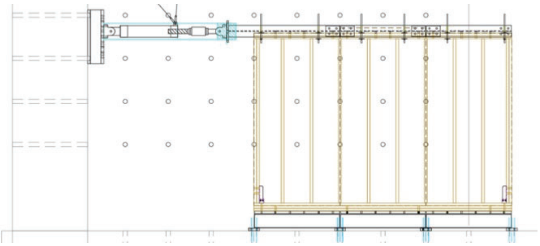

Figure 2: *Elevation view of experimental test setup*

The two 50.8 mm x 101.6 mm (2"x4") boards were incorporated to provide a realistic connection between the bottom plate and frame base. The single bottom plate of shear wall is nailed to the 50.8 mm x 101.6 mm (2"x4") plates using 76.2 mm x 3.33 mm (3"x0.131") nails at 152 mm (6") on center to resemble the connections used in practice and to lessen the influence of the support stiffness on the shear wall stiffness and ultimate capacity.

A hydraulic actuator was used to impart the lateral load during the testing sequence. Connected to the actuator, the load spreader acts as the mechanism imparting the horizontal force of the actuator to the wall specimen. The load spreader consisted of three W10x30 beams, situated such that the beam web rests on the top plate of the wall. The W10x30 beams were connected at each end using 12.7 mm (½") plates and 8 bolts on each side.

To connect the load spreader and the shear wall, 300 mm long, 19.05 mm diameter (1'-0", 3/4") rods were threaded through the beam web holes and corresponding holes in the shear wall double top plate. The rods were anchored to the shear wall top plate using a plate washer and nut on either end, such that the rod could not move, and the load spreader sits directly on the nut. A brass bushing was threaded through the hole in the beam web to ensure no slippage laterally between the rod and the load spreader. However, vertical movement was allowed as there was no restraint above the load spreader. The purpose of this connection was to prevent the stiffness of the load spreader from impacting the wall behavior.

To eliminate out-of-plane movement by the shear wall during testing, additional bracing was provided by roller bearings along the top of the framing system. As shown in Figure 3, roller supports were spaced every 1.22 m (4 feet) and positioned to be in contact with the flanges on both sides of the load spreader beam. A total of 6 rollers were mounted on columns anchored to the strong floor and cantilevers anchored to the strong wall.

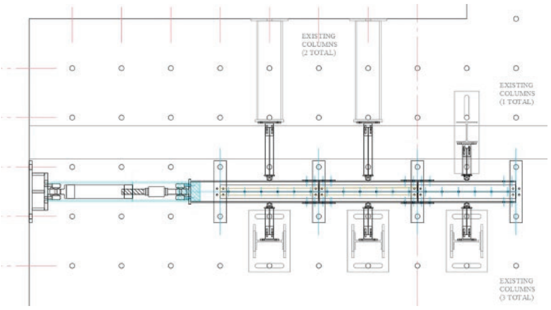

Figure 3: *Plan view of experimental test setup*

4.2 TESTING PROTOCOL

ASTM E2126-11, Test Method C, the CUREE Basic Loading Protocol was used for all tests. The basis for the loading sequence is a reference displacement founded on the maximum displacement, D, for which the specimen exhibits acceptable behavior when undergoing the given protocol. Alternatively, it can be described as a fraction of the reference displacement D_m, the displacement where the load of the primary cycle remains greater than 80% of the ultimate load on the degradation portion of the monotonically loaded curve. The reference displacement cannot exceed 1/40 the height of the wall, or 60.96 mm (2.40 in.) for the given specimen. For these tests, 60.96 mm was used. Figure 4 provides a graphical representation of the procedure.

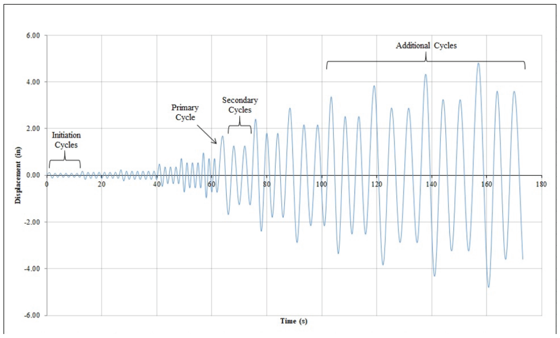

Figure 4: *ASTM E2126-11, CUREE Basic Loading Protocol*

To begin the loading sequence, six low amplitude initiation cycles are performed to allow equipment calibration. Following the first set, the remaining steps have a singular primary cycle amplitude a fraction of the established reference displacement, and several trailing secondary cycles of an amplitude 75% of the primary cycle. The amplitude and cycles for each set of cycles are provided by the standard, and the sequence is performed until failure occurs. Due to loading rate restrictions by the actuator, the frequency of the cycles decreased at higher amplitudes. The first 31 cycles of testing were rated at 0.50 Hz. The remaining cycles were measured as follows: Cycles 32 to 37 (0.25 Hz), and Cycles 38 to 43 (0.2 Hz).

5 EXPERIMENTAL RESULTS

5.1 OSB SHEAR WALL TEST RESULTS

Figure 5 presents the hysteresis plot for OSB shear wall specimen 3. This was typical of the four tests and is characterized by pinched behavior at small displacements with large loops for the primary cycles (1, 7, 14, 21, 25, 29, 32, 35, 38, 41).

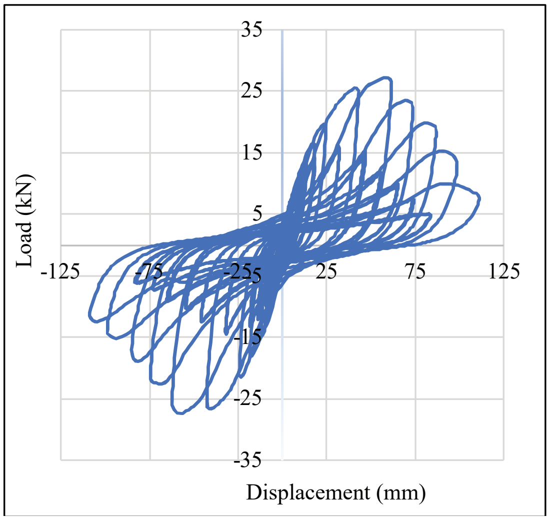

Figure 5: *Typical hysteresis plot for OSB walls (Test 3).*

Table 1 provides a summary for maximum load (P) at each primary step cycle for each shear wall tested, the average load, and the standard deviation. Maximum loads for each shear wall are shown in italic. A maximum average load capacity of 25.9 kN (5.8 k) was achieved during cycle 35 at a displacement of 61.0 mm (2.4 in). Tests were repeatable as evidenced by the standard deviations presented.

There were no visible signs of damage in the OSB walls at displacements below 25.4 mm (1 inch). As displacement levels increased nail pullout along the bottom and seams of OSB walls became evident. Beyond the maximum load, more significant nail deformation was seen, and the sheathing was separated from the frame along some seams and bottom edge. Some nails were broken.

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***Table 1:** Experimental OSB shear wall capacity*

Step	Cycle	Δ	Oriented Strand Board (OSB) Walls					
			1	2	3	4	AVG	STD
		[mm]	P [kN]	P [kN]	P [kN]	P [kN]	P [kN]	P [kN]
1	1	3.0	5.3	5.4	5.5	6.0	**5.5**	0.26
2	7	4.6	6.6	7.0	7.0	7.7	**7.1**	0.38
3	14	6.1	7.6	8.2	8.3	9.0	**8.3**	0.51
4	21	12.2	12.5	13.0	13.0	14.0	**13.1**	0.56
5	25	18.3	16.4	16.6	16.6	17.5	**16.8**	0.41
6	29	24.4	19.3	19.5	19.4	20.6	**19.7**	0.53
7	32	42.7	24.8	25.2	24.7	26.1	**25.2**	0.58
8	35	61.0	*25.1*	*25.4*	*25.9*	*27.3*	***25.9***	0.86
9	38	73.2	21.0	18.0	22.8	23.1	**21.2**	2.02
10	41	80.3	16.8	18.2	19.4	19.4	**18.5**	1.06

***Table 2:** Experimental CFB shear wall capacity*

Step	Cycle	Δ	Cellulosic Fiber Board (CFB) Walls					
			1	2	3	4	AVG	STD
		[mm]	P [kN]	P [kN]	P [kN]	P [kN]	P [kN]	P [kN]
1	1	3.0	5.0	6.6	5.6	6.3	**5.9**	0.62
2	7	4.6	6.5	8.0	7.1	8.0	**7.4**	0.62
3	14	6.1	7.9	9.0	8.7	9.3	**8.7**	0.54
4	21	12.2	12.7	12.9	13.2	13.0	**13.0**	0.18
5	25	18.3	16.4	16.5	17.3	16.3	**16.6**	0.40
6	29	24.4	20.0	19.1	20.8	18.9	**19.7**	0.76
7	32	42.7	*26.6*	*20.6*	*26.0*	*23.1*	***24.1***	2.42
8	35	61.0	26.0	19.4	21.3	19.0	**21.4**	2.80
9	38	73.2	15.1	14.9	14.7	15.1	**14.9**	0.16
10	41	80.3	11.7	10.6	11.4	11.4	**11.3**	0.42

5.2 CFB SHEAR WALL TEST RESULTS

Figure 6 presents the hysteresis plot for CFB shear wall specimen 3. This was typical of the four tests and is characterized by pinched behavior at small displacements with larger loops for the primary cycles compared to the secondary cycles.

Table 2 provides a summary for maximum load (P) at each primary step cycle, the average load, and the standard deviation. Maximum loads for each shear wall are shown in italic. A maximum average load capacity of 24.1 kN (5.4 k) was achieved during cycle 32 at a displacement of 42.7 mm (1.68 in). Tests were repeatable as evidenced by the standard deviations.

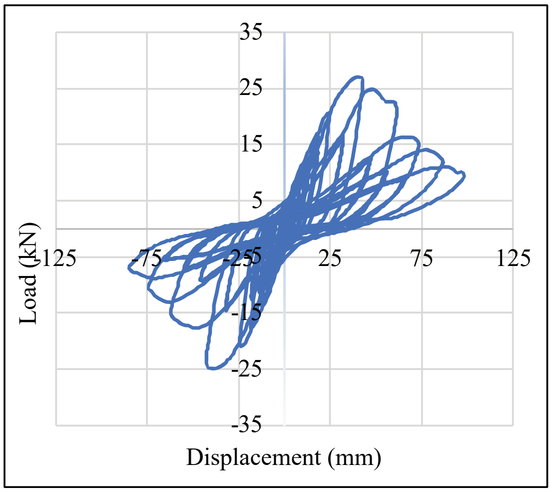

***Figure 6:** Typical hysteresis plot for CFB walls (Test 3).*

There were no visible signs of damage in the CFB walls at displacements below 25.4 mm (1 inch). As displacements increased beyond 25.4 mm (1 inch), the CFB walls exhibited additional damage. Post ultimate load the CFB sheathing buckled between vertical framing studs. Following test completion, residual damage included highly deformed, unattached, and broken staples, as well as buckled sheathing.

5.3 COMPARISON OF OSB AND CFB LOADS

Table 3 presents a comparison of the average shear wall loads corresponding to the primary displacement cycles for both OSB and CFB walls. The percentage difference between the walls is also presented. For displacements below 12 mm (0.5 in) the CFB walls are slightly stiffer than the OSB walls. Between 12 mm (0.5 in) and 24 mm (1 in) the walls have the same load capacity.

The walls reached maximum capacity at different levels of displacement. At a displacement of 42.7 mm (0.47 in) the CFB reaches the maximum capacity of 24.1 kN (5.4 k), while the OSB reaches the maximum capacity of 25.9 kN (5.8 k) at a displacement of 61.0 mm (2.4 in)

***Table 3:** Shear wall capacity and percent difference.*

Step	Cycle	Δ	OSB	CFB	Percent
			Avg Load	Avg Load	Difference
		[mm]	[kN]	[kN]	[%]
1	1	3.0	5.5	5.9	5.7
2	7	4.6	7.1	7.4	4.7
3	14	6.1	8.3	8.7	5.1
4	21	12.2	13.1	13.0	-1.2
5	25	18.3	16.8	16.6	-1.0
6	29	24.4	19.7	19.7	0.1
7	32	42.7	25.2	***24.1***	-4.5
8	35	61.0	***25.9***	21.4	-17.5
9	38	73.2	21.2	14.9	-29.6
10	41	80.3	18.5	11.3	-38.9

Figure 7 presents the data in Table 3 graphically. The load displacement response of the OSB and CFB shear walls is comparable up to a displacement of 42.7 mm (1.68 in). The drift limit used in wood shear wall design is generally far below this level of displacement. Beyond cycle 32 the CFB walls start to lose capacity while the OSB walls continue to carry addition load until cycle 35. Following maximum capacity both walls lose structural capacity; however, the CFB walls deteriorate at a far greater rate. This was verified visually by the damage patterns exhibited during testing as well.

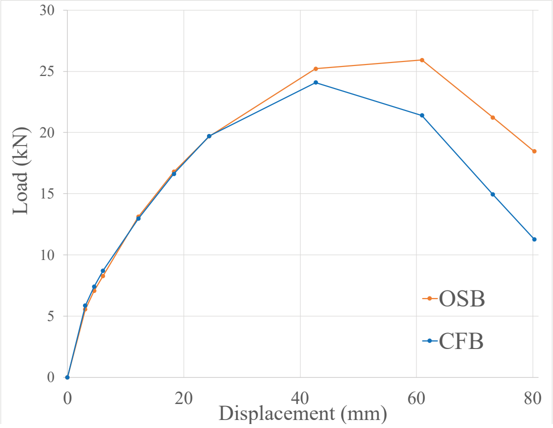

Figure 7: *Backbone plots for OSB and CFB shear walls.*

6 CONCLUSIONS

The four OSB and four CFB walls tested behaved as typical shear walls with repeatable results when subjected to ASTM E2126, Test Method C, CUREE Basic Loading Protocol. It is concluded that the OSB and CFB walls were structurally equivalent up to approximately 42.7 mm (1.68 in) of wall displacement.

The OSB average maximum load was 25.9 kN (5.8 k) at a wall displacement of 61 mm (2.4 in) (cycle 35), while the CFB average maximum load was 24.1 kN (5.4 k) at a displacement of 42.7 mm (1.68 in) (cycle 32). The CFB walls lost capacity at a faster rate than the OSB walls beyond the maximum load as the sheathing buckled.

Additional testing of shear walls sheathed with CFB is needed to verify comparable performance to OSB for other conditions, such as large window and door openings and/or alternative loading sequences.

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