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A Study on the Lateral Mechanical Behavior of the Poplar Laminated Veneer Lumber Shear Wall

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Abstract

Laminated Veneer Lumber (LVL) is engineered product produced by adhesively bonding fast growing Poplar veneers. Comparing dimensional lumber, LVL provides better use rate and fulfills structural wood requirement for wood structure building. And have proven this thing about the lateral mechanical properties for LVL shear walls, also have done investigations into what the hold downs and the loads of those that get put into it do to them when trying out these types of things in an effort to study their lateral mechanical workings. Comparisons with different types of wooden shear wall structures were carried out for this reason. According to the research data obtained through experiments and analyses, suggestions were proposed to designers regarding how they might go about designing hold-down devices in cases wherein these were employed with respect to particular kinds of shear walls which themselves had their own particular features and attributes.

Keywords: wood shear wall; mechanical performance; hold-down; rigid

1. Introduction

The current shortage of wood material supply restricts the development of wooden structure buildings. Under the current situation, studied about physical, mechanical property of poplar LVL and material characteristic by material test.

Currently, the yield of dimension lumber does not exceed 30%, indicating low wood utilization. Poplar LVL is a sustainable modern engineered wood product made from fast-growing poplar wood through veneer slicing, gluing, and hot pressing. It features high toughness, good durability, and easy processing. The wood utilization rate of LVL can reach 80%. If it can replace dimension lumber in wood-framed buildings, it will effectively address the issue of low material utilization in such structures.Liu Yan[1]studied the physical and mechanical properties of poplar LVL and analyzed its material characteristics through material tests. The results showed that LVL exhibits limited plastic deformation under tension or compression, with a linear stress-strain relationship and uniform material properties, making it suitable for use as a building material.Sun Chao et al.[2]Conducted low cycle reversed loading test on 12 CLT orthotropic glued laminated timber shear wall to investigate the effect of Axial Compression Ratio and Splice Joint on Seismic Performance of CLT Shear wall. And the result has shown that it greatly depends on what's going with things like pulling from the sides as well as twisting, on how much the CLT shear wall can hold up on either side.Liu Weiqing and Yang Huifeng[3]conducted flexural performance tests on LVL beams and analyzed the failure mechanisms and factors affecting the structural performance of LVL beam members. From our findings, we found out that the structual strength holding up an LVL beam is more so with the dimension lumber type.Zhou Chao[4] conducted eccentric compression tests on poplar LVL column specimens and analyzed the failure mechanisms, obtaining a constitutive relationship model between slenderness ratio and compressive performance of LVL columns.Bagheri and Doudak[5]according to the model test results of 26 full-scale timber shear walls, studied how different structures would change the way shear walls worked laterally. Load carrying ability and sticeness is very dependent with height-to-width ratio of shear wall, and there is a close relationship between the two. Changing the number or size of base bolts has minimal impact on the shear wall's overall bearing capacity, while nail diameter and spacing have a significant impact on their mechanical performance.Shadravan et al.[6] researched how reinforcement changed the amount of side movement of wall pieces which were held by forces using tests done on 15 groups of wood shear walls without openings of different sorts. Reinforcement has a great effect on enhancing the resistance to sideswiping power from shearing walls: according Cheng Haijia and others [7]they did experiments on wood shearing walls whose shapes varied in order to see if there was any impact of flanges walls as well as vertical pressure when considering such matters. And the research says that if your vertical load was there then the rest of it will help with the structure. but if you had those vertical load present on the flange part, it does hurt your structural performance.He Minjuan[8]compared test results done with various different thicknesses of domestic OSB board and also tested some shear walls with different sheathing panels attached to them trying to work out what an influence these things might have over the lateral mechanical behaviour of any given wall made by such means. It appears that the mechanical performance for the domestic OSB board shear wall is the same or very near the same as the imported one's from Zheng Wei et al. [9] studied the relationship between the mechanical performance of wood frames and wood shear walls. The test results showed that the sum of the elastic lateral stiffness of wood frames and wood shear walls is close to that of frame-shear walls, but the lateral bearing capacity of frame-shear walls is much greater than the sum of the two.Cassidy et al. [10]ordinary OSB board and FRP board Shear Wall Comparison Study. From results we found out the shear walls with FRP Boards can take care of most of the load and can also withstand more stress and strength and hence we can conclude that these materials are better option for such kind of work.

Based on the advantages of poplar LVL material and the importance of wood shear walls, this paper investigates the structural applicability of poplar LVL shear walls with three different opening forms through monotonic and cyclic loading tests. Also look into the effect that hold down's and load transfer beams have had on the side way movement for shear walls by comparing it to other existing tests.

At present, the current research status of domestic and foreign has laid some basis for the current study of poplar LVL, and the mechanical performance of dimension lumber shear walls has been relatively well studied. However, there has been no experimental research on LVL shear walls. The laterals of the displacement performances of LVL shear walls aren't studied well, I'm going to make up for that part here.

2. Experimental Parameters

2.1. Material Parameters

2.1.1. Physical and Mechanical Properties of LVL

According to "Testing method of bending strength of wood"[11]and the general rules about "Testing methods for Physical and Mechanical property of wood" [12], all kind of the mechanical tests has been performed for LVL. For the whole set up materials used is same as the one in the Shear Wall Test (Laminated Glued Wood) used poplar laminated glued wood and the bond is formed using water based polyisocyanate adhesive(API). [13]. These materials were all sourced from Siyang, Jiangsu Province.

Table 1. shows results of the physical and mechanical tests of the LVL material.

Moisture Content	Density (g/cm^3)	Modulus of Elasticity（MPa）	Bending Strength（MPa）	Compressive Strength（MPa）	Tensile Strength

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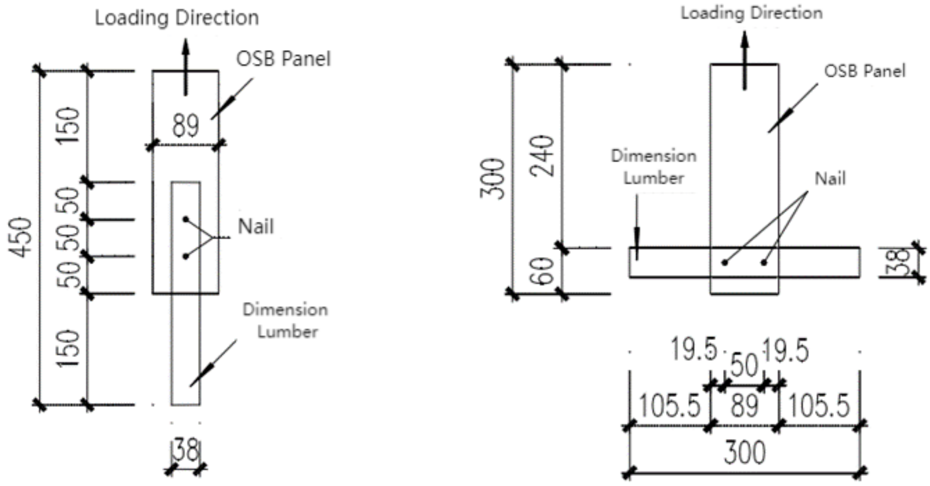
(%)		Parallel to Glue Line	Perpendicular to Glue Line	Parallel to Glue Line	Perpendicular to Glue Line	Parallel to Glue Line	Perpendicular to Glue Line	（MPa）
12.8	0.57	10135.4	9877.3	64.8	61.56	37.03	6.3	39.4

2.1.2. Sheathing-to-Framing Nail Connection Performance

Nailed joints of sheathing with respect to the wall structure on a wood shear wall is a considerable determinant of its mechanical nature.[14]. To investigate the connection strength between the LVL studs and the sheathing, nail withdrawal tests were conducted. Connection tests material batch was also used for laterally performing tests of the LVL Shear Walls. The nales are the Domestic Sakura brand Thread Rolling Fllor nail, thsheething is 9.5mm Oriented Strand board (OSB).

The test is arranged according to LVL stud material's direction and divided into group A and group B; there are ten samples in each group based on their orientation. The configuration for nailing connection specimen and its loading setup are presented in Figure 1. Load – displacement curve for specimen A,B are shown in Figure 2.

The test of nail connecting for the LVL frame - OSB sheathing gives an ultimate displacement along the glue line to be 16.6mm at which point the associated mean ultimate load would be 2.37kN. The average ultimate displacement in the direction perpendicular to the glue line was 14.7 mm, with a corresponding average ultimate load of 2.67 kN.



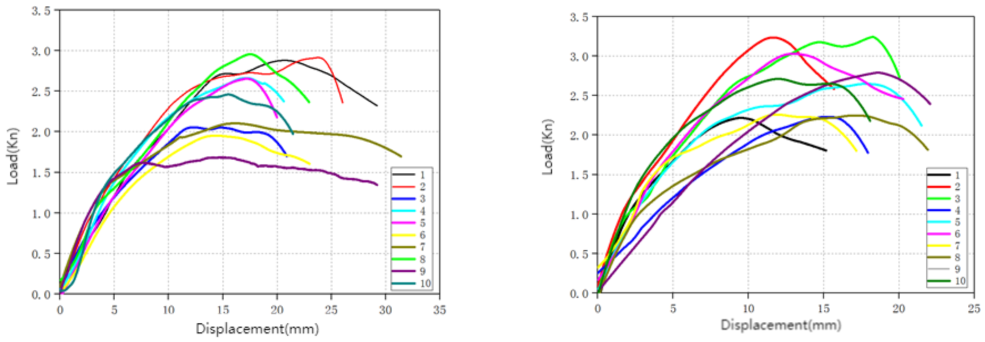
Group A (Parallel to Glue Line) Group B (Perpendicular to Glue Line)

(a) Test Setup (mm)

Group A (Parallel to Glue Line) Group A (Parallel to Glue Line)

(b) Loading Apparatus

Figure 1. Sheathing Nail Connection Test.



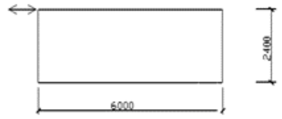
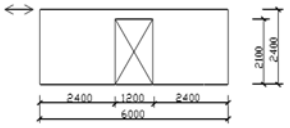
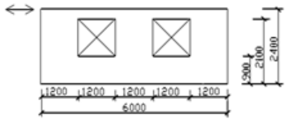
(a) Group A Specimens (b) Group B Specimens

Figure 2. Load-Displacement Curves of Sheathing Nail Connection Specimens.

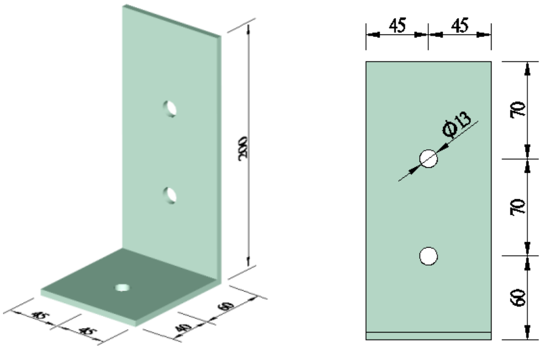
2.2. Shear Wall Specimens

Shear wall specimens tested here were according to code for design of timber structure(GB50005-2003) (GB 50005-2003)[15]. Three specimens named as Wall A,Wall B and Wall C were made taking size, location of wall opening into account. All wall frame is formed by LVL. Sheathing is composed of 9. 5mm thick domestic OSB boards while the fasteners are Sakura brand thread rolling floor nail. Specific configurations of shear walls are shown in Table 2; more precise information may be seen on Figure 4.

Table 2. Specific configurations of the shear walls (mm).

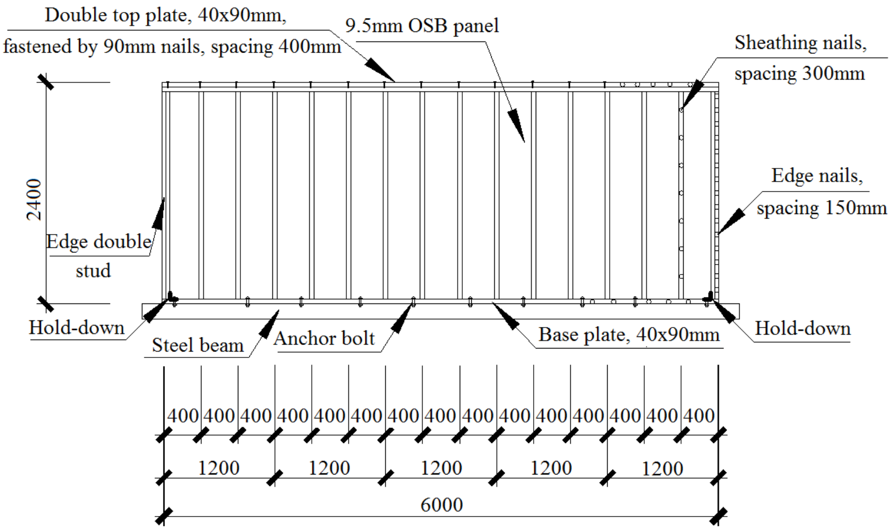
Specimen	Configuration Diagram	No.	Loading Protocol	Opening Type
Wall A		1	Monotonic	Solid
		2	Cyclic	Solid
Wall B		3	Monotonic	1.2m×2.1m Door
		4	Cyclic	1.2m×2.1m Door
Wall C		5	Monotonic	1.2m×1.2m Window
		6	Cyclic	1.2m×1.2m Window

At the corners of the shear wall edges where there are hold-downs, these hold-downs are placed next to the end studs and bottom plate. The hold-downs were fabricated from 5 mm thick Q235 steel, and their dimensions are shown in Figure 3. The detailed configs of spec walls Wall A, Wall B and Wall C are shown in Figure 4.

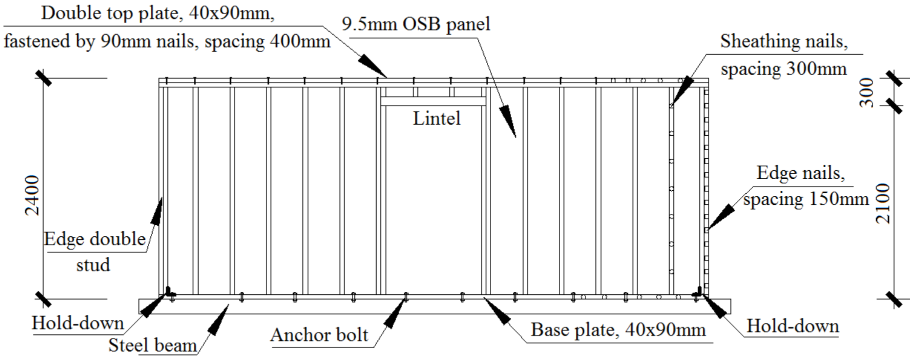


(a) Perspective View (b) Side View

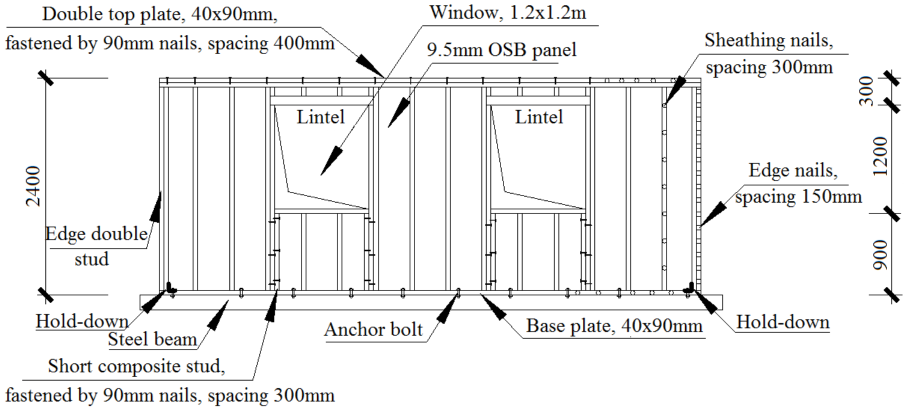
Figure 3. Hold-down Dimensions (mm).



(a) Solid Shear Wall Wall A



(b) Shear Wall Wall B with Door Opening



(c) Shear Wall Wall C with Window Opening

Figure 4. Detailed Configuration and Dimensions of Shear Wall Specimens (mm)2.3 Loading Setup.

In conventional wood shear wall tests, a continuous rigid load transfer beam is often employed for loading. However, in actual light wood frame buildings, the vertical restraint provided by the floor diaphragm on the lower shear walls is typically not significant[16]. And then this kind of rigid load beam that just is not letting go of that vertical movement for the walls at all does mean we're having to try and simulate the things going on in there with these beams being used which doesn't fully match up what we have happening to these walls inside of where they sit amongst each other.

To more realistically simulate the stress state of wood shear walls in a structure, this test adopted a new cantilever-type load transfer device, hereinafter referred to as the out-of-plane loading beam. This device can transfer the horizontal force while not restricting the vertical displacement of the shear wall. In this test, a total of five segmented cantilever-type load transfer devices were installed on the steel beam, as shown in Figure 5.

Test is carried out by the Structural Lab of Yangzhou University. The loading power is provided by the FTS hydraulic servo loading machine. Force was transferred from the hydraulic servo actuator to the load transfer beam, then finally a horizontal displacement was applied via the cantilever type load transfer device on the poplar LVL shear wall.

Figure 5. Out-of-plane Loading Beam.

2.3. Loading Protocol

The loading protocol for this test adopted the ISO-16670 [17] displacement-controlled procedure, without considering the influence of vertical load. In the thrust direction there's a continually increasing load that gets used up by the machine that measures things at a regular speed of seven and half millimeters per minute. The test ended with the load dropping down to 80% of its biggest value. Ultimate displacements were used as the controls during the low cycle reversed cyclic loading with a loading rate 5mm/s(Figure 6).

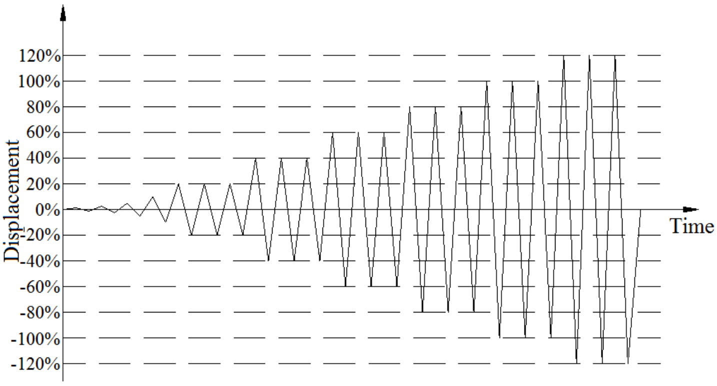


Figure 6. Cyclic Loading Protocol.

3. Results and Analysis

3.1. Failure Modes

Primary failure mode: Poplar LVL shear wall - Sheathing – to – framing nail failure or separation of the sheathing from the wall frame. During the tests, four main failure modes of the sheathing nails were observed: nail withdrawal, nail head pull-through the sheathing, sheathing edge tearing, and nail shear fracture due to fatigue, as shown in Figure 7. Based on observations, nails are positioned along the bottom and sides of the sheathing panels were prone to damage, while nails in the middle and top areas were rarely damaged. Among the four failure modes, nail shear failure caused by fatigue was observed exclusively in the cyclic loading tests.

(a) Bottom Nail Withdrawa

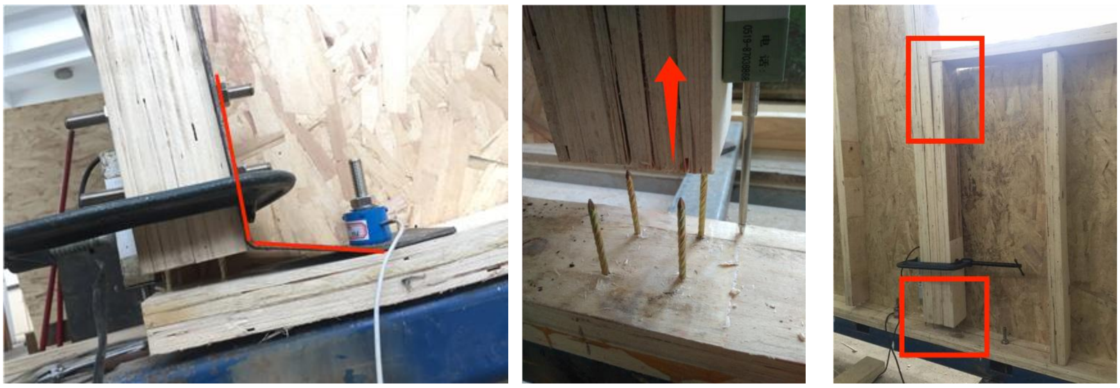
(b) Nail Head Pull-Through the Sheathing at Bottom

(c) Bottom Nail Shear Failure

(d) Edge Nail Shear Failure

Figure 7. Nail Connection Failure Modes.

Difference about whether the distance between studs and sheathing were separated when under single or repeated loads. In monotonic loading tests, the studs located near the loading end experienced uplift, whereas those situated farther from the loading end underwent compression. The uplift of the studs was relatively small, and the overall damage to the shear wall specimens was less severe. Under cyclic loading, the hold down components saw the yield state and also some uplift on the stud for wall A which was noticeable compared with rest of specimens(stud shown as a circle with upward arrow), the wall B and C showed even bigger uplift in stud which were adjacent to the open spots (as indicated by red arrows in figures 8b,8c).



(a) WallA (b) WallB (c) WallC

Figure 8. Separation of Studs from Bottom Plate.

From the observed failure phenomena, it can be concluded that the studs, which are the primary material of the wall frame, did not undergo significant failure themselves. Main failure modes were nail connections failing or nails coming loose from the bottom plates. Guo Yun [18] did monotonic and cyclic tests on poplar DLWSW speci- mens with the same dimensions and configu- ration. Findings show that failure mode of poplar LVL shear walls very similar to those displayed by tradition dimen- sional lumber shear wall[19].

3.2. Main Test Results

All three poplar LVL shear wall specimens demonstrated favorable mechanical performance under both monotonic and cyclic loading. The analysis employed the most conventional parameter definitions currently used[20].The results obtained from this test, including shear strength, ultimate displacement, and others, are presented in Table 3.

Liu Yan[21]conducted lateral performance tests on poplar dimension lumber shear walls using load transfer beams of different stiffnesses. For analysis of how much load transfer beam has on experiment result of shear wall laterally holding capacity, Guo Yun and Liu Yan's data is compared with the current project. Guo Yun's tests employed the same out-of-plane loading beam as used in this study. Liu Yan's tests utilized both segmented pin-connected loading beams and rigid loading beams with different stiffnesses. Both of their tests used poplar dimension lumber and did not incorporate hold-downs; all other structural details, loading protocols, and other variables were consistent with this test.The test results for the shear walls constructed using poplar dimension lumber in Guo Yun's tests are presented in Table 4.

Table 3. Main Test Results for Poplar LVL Shear Walls.

Specimen	Loading Protocol	f_{vd}1（kN/m）			Δu2（mm）			Ke3（kN/m/mm）			E4（J）
		T5	C6	Average	T5	C6	Average	T5	C6	Average	
WallA	Monotonic	9.1	-	9.1	66	-	66	0.35	-	0.35	-
	Cyclic	8.7	7.5	8.1	67	60	64	0.27	0.33	0.3	22629
WallB	Monotonic	5.6	-	5.6	70	-	70	0.27	-	0.27	-
	Cyclic	4.4	5.4	4.9	81	78	80	0.25	0.29	0.27	18392
WallC	Monotonic	9.0	-	9.0	92	-	92	0.29	-	0.29	-
	Cyclic	6.7	8.9	7.8	86	75	81	0.2	0.35	0.28	21273

Table 4. Main Test Results for Dimension Lumber Shear Walls.

Specimen	Loading Protocol	f_{vd}1（kN/m）			Δu2（mm）			Ke3（kN/m/mm）			E4（J）
		T5	C6	Average	T5	C6	Average	T5	C6	Average	
WallA	Monotonic	6.36	-	6.36	51	-	51	0.39	-	0.39	-
	Cyclic	5.81	5.31	5.56	35	38	37	0.40	0.39	0.40	13793
WallB	Monotonic	4.84	-	4.84	57	-	57	0.31	-	0.31	-
	Cyclic	4.65	4.57	4.61	58	58	58	0.34	0.27	0.30	13304
WallC	Monotonic	8.88	-	8.88	60	-	60	0.42	-	0.42	-
	Cyclic	7.19	7.03	7.11	52	51	52	0.46	0.46	0.46	10105

Notes:1. fvd- The unit shear strength of the shear walls in kN/m2. 2) Δu – ultimate displacement of shear wall in mm ; 3) Ke - unit lateral stiffness of shear wall in kN/mm/m ; 4) E - energy dissipation of shear wall in kj ; 5) T - thrust loading direction ; 6) C - tension (pull) loading direction.

In contrast, the overall mechanical performance of all the LVL shear wall samples in this testing were better. Figure 9 presents a comparison of the lateral performance characteristics between LVL shear walls and poplar dimension lumber shear walls under cyclic loading. In the test results can be seen the three poplar LVL shear walls exhibit great increase in the unit shear strength, the ultimate displacements as well as the capacities of energy dissipation over the dimension lumber shear walls even though the unit lateral stiffens are only marginally lower.

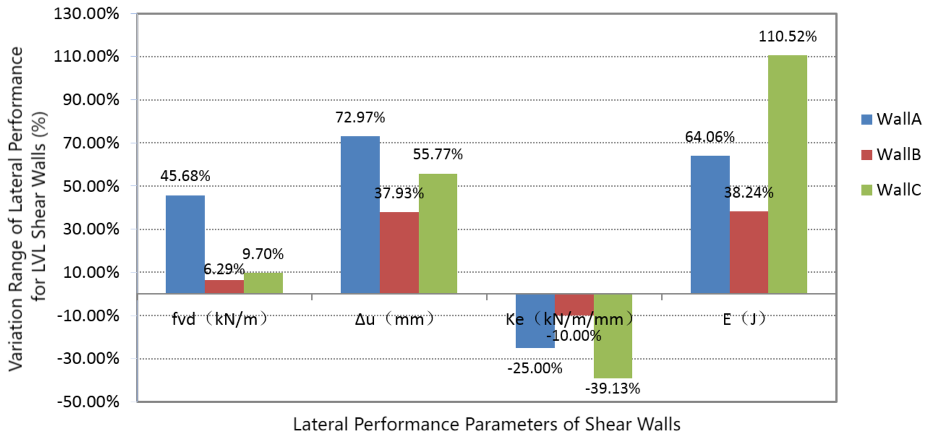
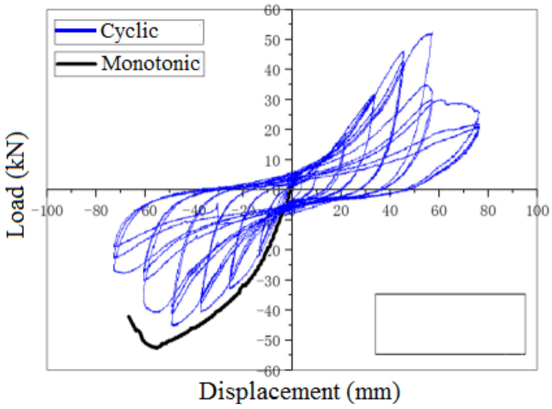


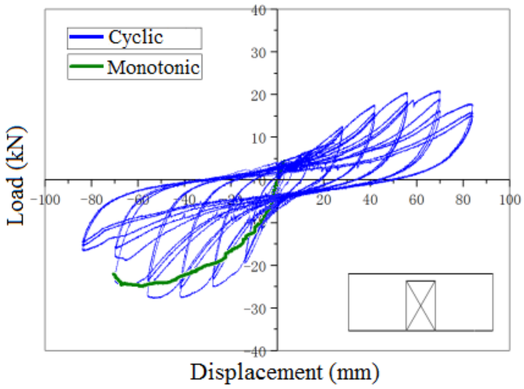
Figure 9. Comparison of Lateral Performance Parameters between LVL and Dimension Lumber Shear Walls.

3.2.1. Load-Displacement Curves

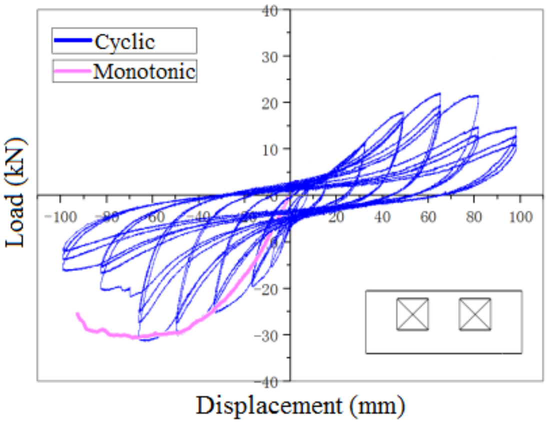
In contrast, the overall mechanical performance of all the LVL shear wall samples in this testing were better[22].In the test results can be seen the three poplar LVL shear walls exhibit great increase in the unit shear strength, the ultimate displacements as well as the capacities of energy dissipation over the dimension lumber shear walls even though the unit lateral stiffens are only marginally lower. The primary characteristics include an increasing secant slope of the load-displacement curve with increasing load amplitude, while the slope within each individual cycle decreased. After multiple cycles, inflection points began to appear on the load-displacement curves, representing the degree of stiffness loss in samples. The unloading curves initially were nearly vertical, indicating minimal deformation recovery.However, as unloading progressed further, the curves flattened, and the deformation recovery rate gradually increased, demonstrating significant hysteresis in the deformation recovery process.



（a）WallA



（b）WallB



（c）WallC

Figure 10. Load-Displacement Curves.

3.2.2. Unit Shear Strength

In previous similar experiments, the structural forms, dimensions and opening patterns of the shear walls studied might have been different. But it is supposed that strength and hardness of the shear wall are directly proportionate with effective length of the wall limb of the test sample wall [23].where Fmax is the largest load obtained by the monotonic loading test and l is the effective length of the wall limb without opening inside the total height of the shear wall[24].

Analysis of these findings indicates that when we compare the shear strengths between Solid Wall A which is without any doorway and Wall B having a doorway but no windows it reduces its shear strength by about 38%. And in terms of Wall C which includes Window openings has lost just only 1.5% of the original strength that was present before with Wall. This discrepancy is attributed to the strengthening effect provided by the wall segment beneath the window opening in Wall C[25]. The failure mode observed after loading indicated that the wall section below the window opening experienced substantial damage and resisted significant external forces (as shown in Figure 11). In contrast, for the door-opened specimen Wall B, the lateral forces at the opening were resisted solely by the door frame studs, resulting in severe uplift of these studs and premature overall failure of the specimen, leading to lower shear capacity (as shown in Figure 11). This indicates that incorporating a door opening in a wood shear wall creates a significant weak point that adversely affects the load-bearing capacity, on the other hand, the influence of a window opening to the shear force resistance property of the shear wall can be considered negligible.

Torsion of Sheathing below Window

Uplift of Stud on One Side of Door Opening

Figure 11. Observed Failure in Perforated Specimens.

The unit shear strength results for solid shear walls under different conditions of load transfer beam type and hold-down usage are presented in Table 5. Comparing the test results of Wall A (with

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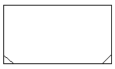
hold-downs) and Wall A1 (without hold-downs), Adding hold-down's raised the wall's shear capacity by 43% so hold-downs have a major part to play if you want to have better shear capacities on those walls made from wood, that was the take-home message.

With respect to the effect of load transfer beam, it was ascertained that wall A2, the one that made utilization of the segmented pin-connecting loading beam, achieved the figure of shear capacity amount being greater by 11.5percent when as compared to the figure derived under the context where wall A1 adopted such a load transfer technique that operated along an out-of-plane axis. Meanwhile, Wall A3, which used the rigid loading beam, exhibited a 36.7% increase in shear capacity. This suggests the improvement of shear strength for the shear wall from experiments with more stiff beam to carry the load.

Table 5. Unit Shear Strength.

Identifier	WallA 	WallA1 	WallA2 	WallA3 
Load Transfer Beam Type	Out-of-plane Load Transfer Beam	Out-of-plane Load Transfer Beam	Segmented Pin-connected Loading Beam	Rigid Loading Beam
Hold-down Used?	√	/	/	/
Unit Shear Strength (Monotonic) (kN/m)	9.1	6.36	6.4	8.1
Unit Shear Strength (Cyclic) (kN/m)	8.1	5.56	6.2	7.6

Hold-downs being used as well as the load transfer beam stiffening can considerably improve the shear strength of the shear wall. As we observe from our experiment, the shear strength of the wall would be increased if the load transfer beams were made more rigid; however, that benefit was nowhere near that of putting hold down.

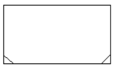
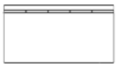
3.2.3. Ultimate Displacement

In this test, the ultimate displacements for specimens A, B, and C under monotonic loading were 66 mm, 70 mm, and 92 mm, respectively. Clearly, the ultimate displacement of shear walls with openings exceeds that of solid walls. In particular, Wall C exhibited a 39% greater ultimate displacement compared to Wall A. This behavior can be attributed to the aspect ratio: as the length of the effective wall segment decreases, the increased aspect ratio promotes greater deformation tendency, resulting in higher ultimate displacement[26].

Table 6 presents the ultimate displacement results for solid shear walls under different conditions of load transfer beam type and hold-down usage. Wall A (with hold-downs) had a 30% higher ultimate displacement than Wall A1 (without hold-downs), indicating that for shear walls of identical construction, the use of hold-downs can significantly enhance the ultimate displacement.

Regarding the influence of the load transfer beam, the ultimate displacement result for Wall A2, which used the segmented pin-connected loading beam, was 25% higher than that of Wall A1, which used the out-of-plane load transfer beam. In contrast, Wall A3, which used the rigid loading beam, exhibited only a 5.8% increase in ultimate displacement. It shows that increasing the load transfer beam stiffness somewhat results in a bigger measured ultimate displacement value for tests. But if we keep making that beam with those load carrying parts more firm (or harder to bend), then the most it gets moved by (the ultimate displacement) goes down. Because the fully-rigid load-transfer beam prevents the shear-wall from undergoing any vertical deformation which imposes too much vertical loading and specimen fail before seeing a big amount of lateral movement [27].

Table 6. Shear Wall Ultimate Displacement.

Identifier	WallA 	WallA1 	WallA2 	WallA3 
Load Transfer Beam Type	Out-of-plane Load Transfer Beam	Out-of-plane Load Transfer Beam	Segmented Pin-connected Loading Beam	Rigid Loading Beam
Hold-down Used?	√	/	/	/
Unit Shear Strength (Monotonic) (kN/m)	66	51	64	54
Unit Shear Strength (Cyclic) (kN/m)	64	37	54	47

The final result is compared to each other for the biggest possible move. It will turn out that we have significantly increased our maximum wood shear wall moves with this extra bit called hold down's added in there. As opposed to the effects brought about by growing the rigidity of the load carrying beam towards obtaining its largest possible shift, it is observed there is first an increase then a drop in it. This is due to the fact that after the stiffness of the load transfer beam has grown, the specimen is subjected to greater vertical pressure during loading. This also explains why the shear wall specimen using the rigid loading beam exhibited high shear capacity but a relatively small ultimate displacement.

3.2.4. Elastic Lateral Stiffness

Elastic lateral stiffnessKeis described by how sloped a straight path drawn from (0,0) up to where our diagram touches a displacement of h/250 along with heights h of these specific shear walls would be[28], see Figure 12. The elastic lateral stiffness of three LVL shear wall specimens for this test was 0.30, 0.27, 0.28kN/mm/m. This indicates that under the same test setup, the lateral stiffness of shear walls with different configurations did not differ significantly.

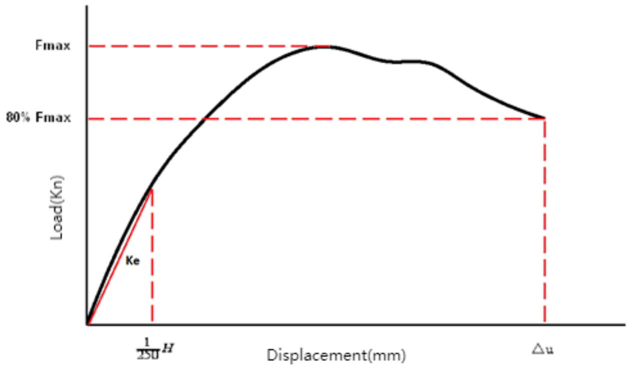
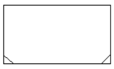
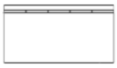


Figure 12. Schematic Diagram of Load-Displacement Curve.

Table 7 presents the elastic lateral stiffness results for solid shear walls under different conditions of load transfer beam type and hold-down usage. The elastic lateral stiffness calculation uses the point on the load-displacement curve at H/250 displacement, reflecting essentially the initial lateral stiffness.Consequently, the stiffness of the load transfer beam has a considerable influence on the experimental stiffness results. Therefore, Wall A3, which used the rigid loading beam, exhibited the highest lateral stiffness.

Table 7. Shear Wall Lateral Stiffness.

Identifier	WallA 	WallA1 	WallA2 	WallA3 
Load Transfer Beam Type	Out-of-plane Load Transfer Beam	Out-of-plane Load Transfer Beam	Segmented Pin-connected Loading Beam	Rigid Loading Beam
Hold-down Used?	√	/	/	/
Unit Shear Strength (Monotonic) (kN/m)	0.35	0.39	0.38	0.49
Unit Shear Strength (Cyclic) (kN/m)	0.3	0.4	0.37	0.5

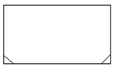
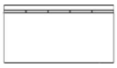
3.2.5. Energy Dissipation

Energy Dissipation expressed as area inside the Hysteresis Loops within a Cyclic loading tests[29]. The energy dissipation results for the three specimens in this test were 22.63 kJ, 18.39 kJ, and 21.27 kJ, respectively. Given that the solid wall specimen Wall A exhibited a higher load-bearing capacity and the windowed wall specimen Wall C demonstrated a greater ultimate displacement, both the solid and windowed shear walls showed superior total energy dissipation compared against the same shear wall but instead has a door opening.

Table 8 presents the energy dissipation results for solid shear walls under different conditions of load transfer beam type and hold-down usage. And we see the amount of energy dissipating is quite large now and when it has these hold downs as seen with the wall A having 64 percent more energy going out than just wall A1 on its own. Compared to specimen Wall A1, the energy dissipation of Wall A2, which used the segmented pin-connected loading beam, showed a slight increase. In contrast, the energy dissipation, E, of Wall A3, which used the rigid loading beam, decreased.

Hold-downs make the energy that is being dissipated by the shear walls go up significantly and this improves the strength and the safety when it comes to earthquakes.The influence of the load transfer beam on energy dissipation is similar to the phenomenon observed for the ultimate displacement: Energy dissipation sees slight growth at first upon enhancing the load transfer beams stiffness but then goes down when there is even more rise in the stiffness.

Table 8. Shear Wall Energy Dissipation.

Identifier	WallA 	WallA1 	WallA2 	WallA3 
Load Transfer Beam Type	Out-of-plane Load Transfer Beam	Out-of-plane Load Transfer Beam	Segmented Pin-connected Loading Beam	Rigid Loading Beam
Hold-down Used?	√	/	/	/
Energy Dissipation (J)	22629	13793	15385	11898

4. Load-Bearing Capacity Calculation

As far as I know some study background exists in regards to the load-carrying ability of dimensional lumber shear walls in China or elsewhere. And according to the idea put forward by Ni Chun[30], we could compute the amount that a section of this sort of structure is able to bear laterally in sum with all the different areas comprising it just like Figure 13 demonstrates.

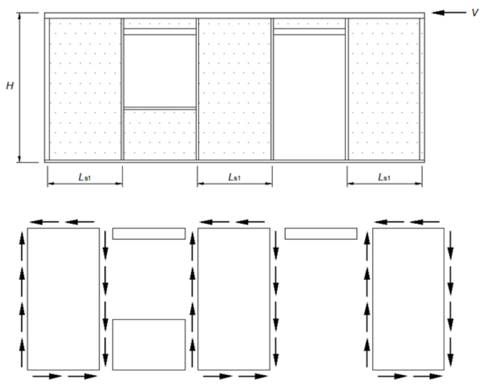


Figure 13. Schematic Diagram for Shear Wall Load-Bearing Capacity Calculation.

sing below Equation we can determine laterall load carrying capacity of shear wall:

$$V = \sum J_{hd} V_d L_s \tag{1}$$

Where:

V is the ultimate lateral load-bearing capacity (kN);

V_d is the unit shear strength of the wall segment (kN/m);

L_s is the length of the wall segment (m);

J_{hd} is the influence coefficient of the hold-down.

If there's a single corner for the local wall segment with just one hold-down, the equivalent calculations can take place (Figure 14).

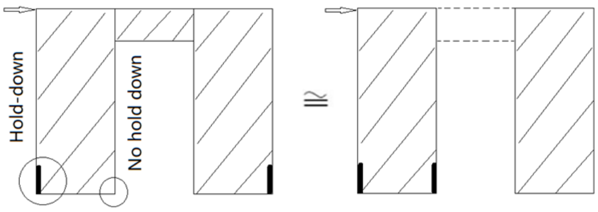


Figure 14. Equivalent Calculation Method for Shear Wall with Hold-down at One Corner.

For the coefficient Jhd, when the wall segment has hold-downs at all corners (or has adjacent wall sections below an opening), take $J_{hd} = 1.0$. If there is no hold down on either side of the wall, then we will have Jhd which goes like this:

$$J_{hd} = \frac{1}{1+3\frac{H}{L_s}} \tag{2}$$

Where:

H is the height of the wall segment (m);

L_s is the length of the wall segment (m).

Parameters that come out of an LVL shear wall test will be fed into this equation here to check if our computation hypothesis holds up or not. Unit shear strength Vd for Wall A is 9.12 kN/m from the test. Wall B door opening two sides' wall parts were all 2.4m. Three wall sections from wall C all have a measurement of 1.2 meters each. Taking into account the previous specimen dimension along with what was previously discussed, then we could assume that it should be possible for us to derive a lateral loading capacity for all remaining specimens from that single solid specimen's wall "A"'s unit shear strength.

The wall B, on its side it is actually formed by the 2 wall pieces which both have height and length being 2.4 meters but with only one of these wall segment has a hold down attached to it and the rest isn't. The calculated lateral load-bearing capacity for Wall B is 27.36 kN. Wall C is considered to be made up by three walls which have a length of 1.2m and height 2.4m each. Since Wall C has a wall section beneath the window opening, the hold-down influence coefficient Jhd for the wall segments adjacent to the opening is taken as 1.0. The calculated lateral load-bearing capacity for Wall C is 32.83 kN. The theoretical predictions for Wall B and Wall C show excellent agreement with the experimental results from this study, indicating that the formula is effective in assessing the load-bearing capacity of poplar LVL shear walls when hold-downs are present.

The mathematical model of the hold-down influence coefficient Jhd is shown in Figure 15. It can be observed that when a shear wall segment has no hold-downs, the decrease in lateral load-bearing capacity is less pronounced for wall segments with lower height and greater length; the length of the shear wall on Jhd has special importance. This indicates that omitting hold-downs in tall and short wall segments (high height-to-length ratio) within a shear wall will result in a significant attenuation of the lateral load-bearing capacity.

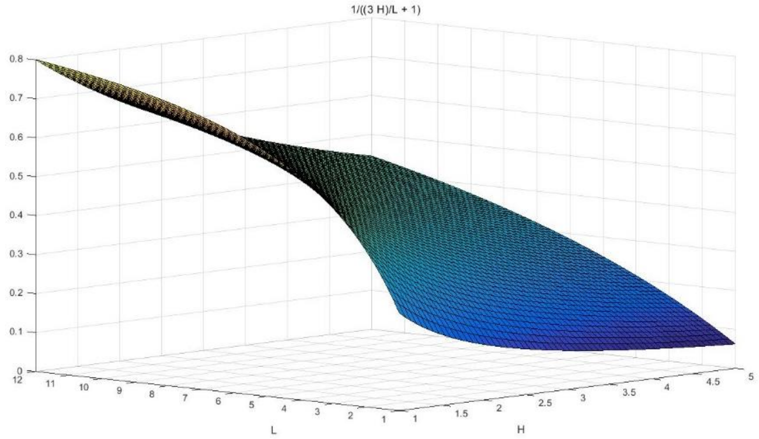


Figure 15. Mathematical Model of Hold-down Influence Coefficient J_{hd}.

As for the test sample which has doors opened up there was just two holds placed at each end of it as for those places which were close by to its sides they weren't present at all. According to theory model, after equivalent transformation, the wall segment near the door opening is like a tall, short piece without hold downs. Lateral load bearing capacity of this section will greatly decrease so that the overall load bearing capacity of the shear wall [31].will be reduced. And we have our observations from the experiment that the door opened shear wall (wall B) will result to have the smaller value than that of wall c having a window on it when we put side pressure on both of these walls.Based on this established pattern, it is recommended in the design of wood shear walls to strengthen corners of tall and short wall segments (characterized by a high height-to-length ratio) by installing hold-downs.

5. Conclusions

(1) The failure modes of poplar laminated veneer lumber (LVL) shear walls are comparable to those of dimensional lumber shear walls, primarily including nail connection failure (sheathing-to-framing) and separation of studs from the bottom plate. The poplar LVL studs and other framing members themselves exhibited no significant failure, indicating good overall structural integrity.

(2) The poplar LVL shear wall specimens equipped with hold-downs demonstrated significantly higher ultimate displacement,unit shear strength,and energy dissipation capacity compared to poplar dimension lumber shear walls, although the unit lateral stiffness was slightly lower. Lateral stiffness calculation mostly represents the beginning rigidity therefore the difference hardly matters in regard to the whole mechanical performance of the shear wall.

(3) Stiffness of the load transfer beams and holds-down configuration has effect on results from testing shear walls. Load transfer beam stiffness is directly proportional with experimentally obtained shear strength. Holding downs make the final displacement, shearing force and power absorption more, but have no good result with elastic sideways strength.

(4) The calculation theory established for perforated dimension lumber shear walls is also applicable to LVL shear walls. Based on the characteristics of the hold-down influence coefficient (J_{hd}) in the calculation formula, shear wall segments with greater height and shorter length exhibit greater dependence on hold-downs. Therefore, in shear wall design, it is recommended to reinforce the corners of such wall segments (characterized by high height-to-length ratios) by installing hold-downs to effectively enhance the wall's lateral load capacity.

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