Lateral Load Carrying Capacities of Particleboard Shear Walls Made by Gluing with Timber Studs

Sung-Jun Pang,[a] Han Shik Lee,[b] and Jung-Kwon Oh [a,c,*]

Particleboard shear walls were developed and their lateral load carrying capacities were evaluated. The shear walls were made by connecting particleboards and timber studs with polyurethane (PUR) or nails. Seven types of particleboard shear wall specimens were manufactured by varying the wood species, size of the timber studs, and number of particleboards. The size of the shear wall specimens was 2.4 m × 2.7 m, and the bottom of the shear wall was fixed to the steel frame of the test equipment using hold-downs and angle brackets. As a result, the lateral load carrying capacities of the glued particleboard shear wall (73.4 to 75.6 kN/m) were 3.2 times higher than that of the typical light-frame shear wall and higher than the experimental data of the cross-laminated timber (CLT) wall in the CLT handbook. All glued specimens failed at the hold-down and angle bracket, and there was no damage at the glue layer between a particleboard and timber studs. The shear performance with different combinations of species, stud size, and number of particleboards was not significantly different, and the shear strength of the nailed specimen was approximately 20% lower than that of the glued specimen.

DOI: 10.15376/biores.18.1.1072-1095

Keywords: Particleboard; Shear wall; Wood; Glue; Lateral capacity

*Contact information: a: Department of Agriculture, Forestry and Bioresources, Seoul National University, Seoul, Republic of Korea; b: Kyung Min Industrial Co., Ltd., Incheon (Gajwa-dong), Republic of Korea; c: Research Institute of Agriculture and Life Sciences, Seoul National University, Seoul, Republic of Korea; * Corresponding author: jungoh@snu.ac.kr*

INTRODUCTION

Wood is a bioresource material that can be recycled and reused (Asdrubali *et al.* 2017). Among the various wood products, particleboard can be made from small-diameter wood, thin-cut wood, or waste wood. Thus, particleboard is an effective method to utilize various biological resources, and various related studies have been reported. De Almeida *et al.* (2017) made the wood-bamboo-based particleboard and evaluated its mechanical properties. Bekhta *et al.* (2013) evaluated the properties of the wood-straw-based particleboard. Hashim *et al.* (2012) evaluated the mechanical properties of particleboard panels manufactured from oil palm. They evaluated the mechanical properties of the new particleboard itself.

Wood products generally have a low environmental impact because of their low carbon emissions and sustainability (Gerilla *et al.* 2007; Yan *et al.* 2010; Hafner and Schäfer 2018; Sandanayake *et al.* 2018; Li *et al.* 2019; Röck *et al.* 2020). Wooden buildings use a large amount of wood for a long time, and the use of wood products contributes to the reduction of released carbon when it is incorporated into buildings (Petersen Raymer 2006; Resch *et al.* 2021). Generally, the CLT is used as a shear wall in mid-and high-rise timber buildings (Polastri *et al.* 2019; Stazi *et al.* 2019). The CLT uses a lot of solid wood. Therefore, in Korea, where solid wood is more expensive than concrete, CLT is less economical than reinforced concrete. Particleboard is less expensive than solid wood because it can be made from worthless wood. When particleboard is used as a sheathing panel in a light-frame timber shear wall, bearing damage around nails (Germano *et al.* 2015) or nail penetration can happen (Yue *et al.* 2022). These types of shear walls may not be strong enough for use in high-rise buildings.

It is proposed that by the use of an adhesive to attach the particleboard panels to the timber studs, it may be possible to exceed the load capacity that can be achieved with conventional nail connections. The binding function of the adhesive can be extended to the entire area of the shear wall, and experimental studies on actual walls are required to confirm the binding function. In this study, particle shear walls were designed by gluing with timber studs, and their lateral load carrying capacities were evaluated. The lateral load carrying capacities according to species, stud size, number of particleboards, and production methods (adhesive, nail) were analyzed.

EXPERIMENTAL

Materials

Shear wall specimens

To experimentally analyze the binding function of the adhesive to the actual particleboard shear walls, test specimens were prepared by varying the species and the size of timber studs, and the number of particleboards. Additionally, a light-frame timber shear wall and a particleboard shear wall made of nails were also fabricated as a control group.

Table 1 shows the combination of test specimens. Seven types of particleboard shear wall specimens were manufactured by varying the wood species, size of the timber studs, and number of particleboards. The specimen ID in Table 1 indicates the wall configurations. The first letter and number indicate the species and width of timber studs. The second term indicates the connection method between particleboards and timber studs. The letter P and N means polyurethane (PUR) and nail, respectively. In No. 7, the connection between particleboards and studs was reinforced with wooden nails (LIGNOLOC® F60, Mauerkirchen, Austria) because the PUR strength of the PUR may not be sufficient. The third term indicates the number of particleboard layers.

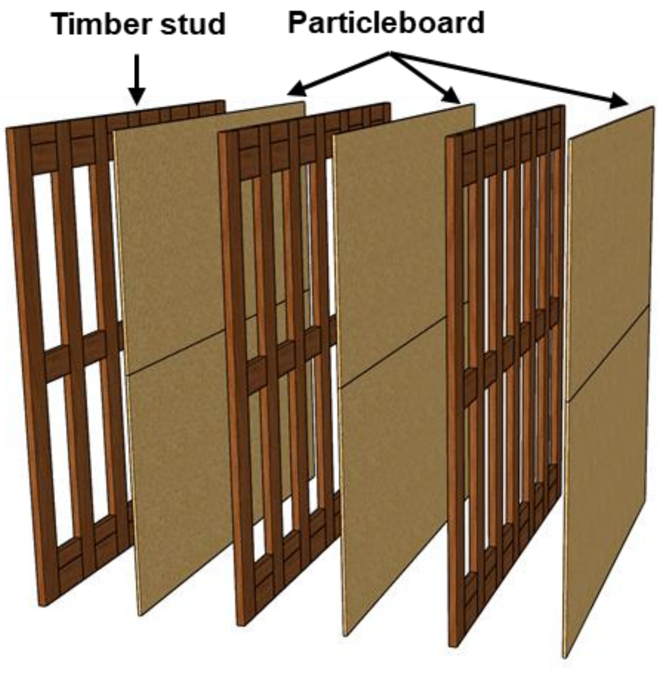
Table 1. Combination of Test Specimens

No.	Specimen ID	Stud (mm)				PB layer	Connection Method	Specimen Size (mm)		
		Species	Grade	Thickness	Width			Thickness	Width	Height
No. 1	L[1)](140)[2)]-P[3)]-2L[4)]	Larch	2nd	38	140	2	PUR[5)]	144	2400	2700
No. 2	S(140)-P-2L	Spruce	2nd	38	140	2	PUR	144	2400	2700
No. 3	L(89)-P-2L	Larch	2nd	38	89	2	PUR	144	2400	2700
No. 4	L(140)-P-3L	Larch	2nd	38	140	3	PUR	159	2400	2700
No. 5	L(140)-P-4L	Larch	2nd	38	140	4	PUR	174	2400	2700
No. 6	L(140)-N-2L	Larch	2nd	38	140	2	Nail (8d@150)	144	2400	2700
No. 7	L(89)-PW-2L	Larch	2nd	38	89	2	PUR + Wood nail	144	2400	2700
No. 8	Light-frame shear wall	Larch	2nd	38	140	2	8d@150, Stud spacing 400 mm	162.2	2400	2700

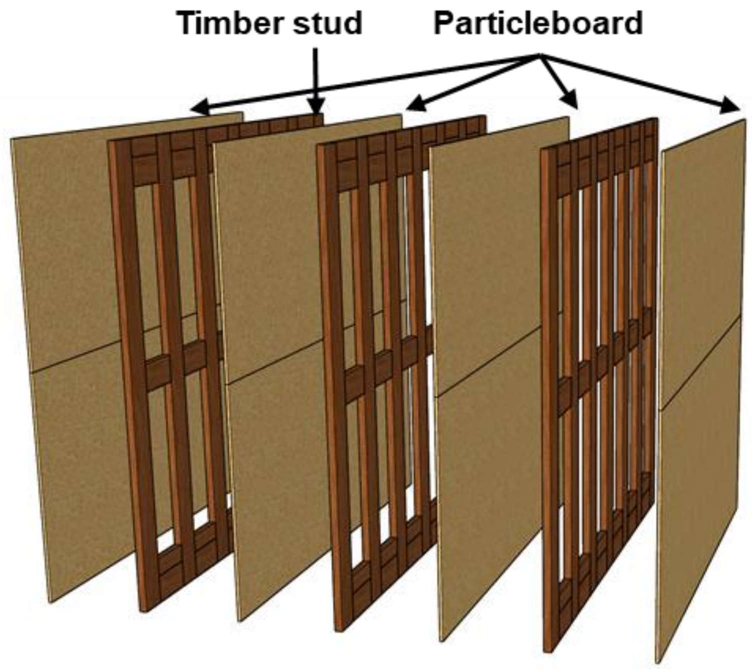
1) species of stud: L = larch, S = spruce;
2) width of stud: 140 = 140 mm, 89 = 89 mm;
3) connection method between timber stud and particleboard: P = polyurethane (PUR), N = nail, PW = PUR and wooden nail;
4) the number of particleboard layers: 2L = two layers, 3L = three layers, 4L = four layers;
5) polyurethane

To compare the lateral load carrying capacities of the particleboard specimens (No. 1 through No. 7) with those of a typical light-frame shear wall, the light-frame shear wall specimen (No. 8) with oriented strand board (OSB) sheathings was prepared. Figure 1 shows the layer combination of test specimens. The thickness of the test specimens depends on the number of boards used, but the width and height are all the same (2400 mm × 2700 mm). One test specimen was produced for each condition.

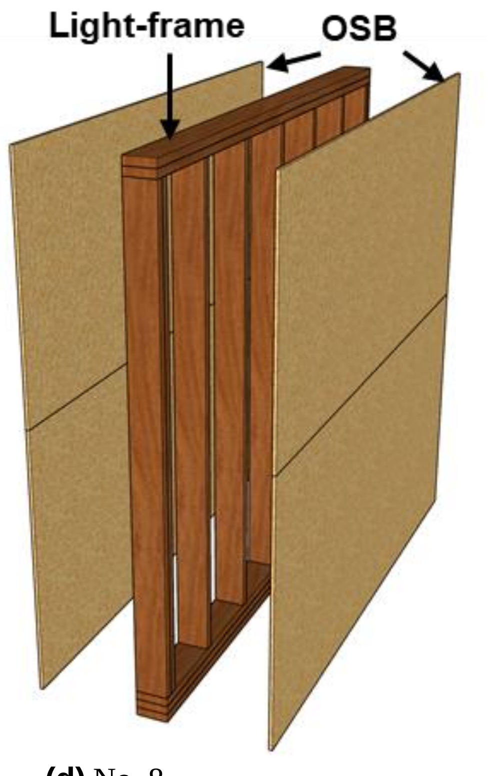
(a) No. 1, No. 2, No. 3, No. 6, and No. 7



(b) No. 4



(c) No. 5



(d) No. 8

Fig. 1. Layer combination of test specimens

Figure 2 shows the particleboard shear wall panels manufactured by Kyung Min Industrial Co., Ltd. (Incheon, Republic of Korea) for prefab construction. Larch laminas (*Larix kaempferi* Carr.) were used for the timber studs for all specimens except for the No.

2 specimen. The No. 2 specimen used European spruce laminas (*Ips typographus* L.) for the timber studs. Structural lumber (2nd visual grade, moisture contents: 12 ± 2%) according to NIFoS #2020-3 (2020) was used. The thickness of particleboard (Daesung Wood, Incheon, Republic of Korea) and OSB (rated sheathing grade, Georgia-Pacific LLC, Atlanta, GA, USA) was 15 mm and 11.1 mm, respectively. The PUR adhesive was used to glue the flatwise surface of timber studs and particleboards in No. 1 through No. 7, except for No. 6. The edgewise and end surfaces of each lamina were not glued. For No. 6 and No. 8, 8d nails (2.8 mm in diameter and 76 mm in length) with 150 mm spacing were used to connect the particleboards and timber studs.

Fig. 2. A picture of particleboard shear wall panel

Shear Wall Test

A shear wall test was conducted to evaluate the lateral load carrying capacities of the specimens. Figure 3 shows a view of the cyclic loading test with a particleboard shear wall panel installed. Both sides of the bottom of the shear wall specimens were fixed to the steel frame of the test equipment using commercial hold-down (WHT 340), and angle-bracket (TCN 200) manufactured by Rothoblaas (Cortaccia (TN), Italy). A hold-down was fixed with the steel frame with a washer (WHTBS50) and a bolt (M16 × 50 mm), and fixed with the particleboard shear wall specimen using 20 screws (Ø5.0 × 50 mm). An angle bracket was fixed with the steel frame only with two bolts (M12 × 50 mm) without washers, and fixed with the particleboard shear wall specimen using 30 screws (Ø5.0 × 50 mm).

The aspect ratio of all shear wall specimens was 1.125 (height: 2.7/width: 2.4). Figure 4 shows the configuration of shear wall specimens and the position of the Linear Variable Displacement Transducers (LVDT). Five actual displacements of the shear wall were measured according to ASTM E564-06 (2018). LVDT 1 was used for the actual displacement of the top of specimens. LVDT 2 and LVDT 3 were used for the lateral displacement of the bottom of specimens. LVDT 4 and LVDT 5 were used for the vertical displacements of the specimens. LVDT 6 was used for the diagonal displacement of the specimens.

Fig. 3. Picture of a shear wall test with a specimen installed

The vertical load (50 kN) was applied on top of all specimens using an actuator (244.22G2 model, MTS, Eden Prairie, MN, USA). The lateral cyclic loading was applied according to ISO 16670 load protocol in ASTM E2126 (2009) (Method B) using an actuator (244.31G2 model, MTS, USA). The cyclic frequency was 0.2 Hz and Fig. 5 shows the applied displacement history for the shear wall specimens. Load-displacement curve data were obtained while cyclic loading was applied to each specimen according to the loading protocol. The applied load and corresponding displacements of shear wall specimens were recorded at 0.01-s intervals to plot load-displacement curves.

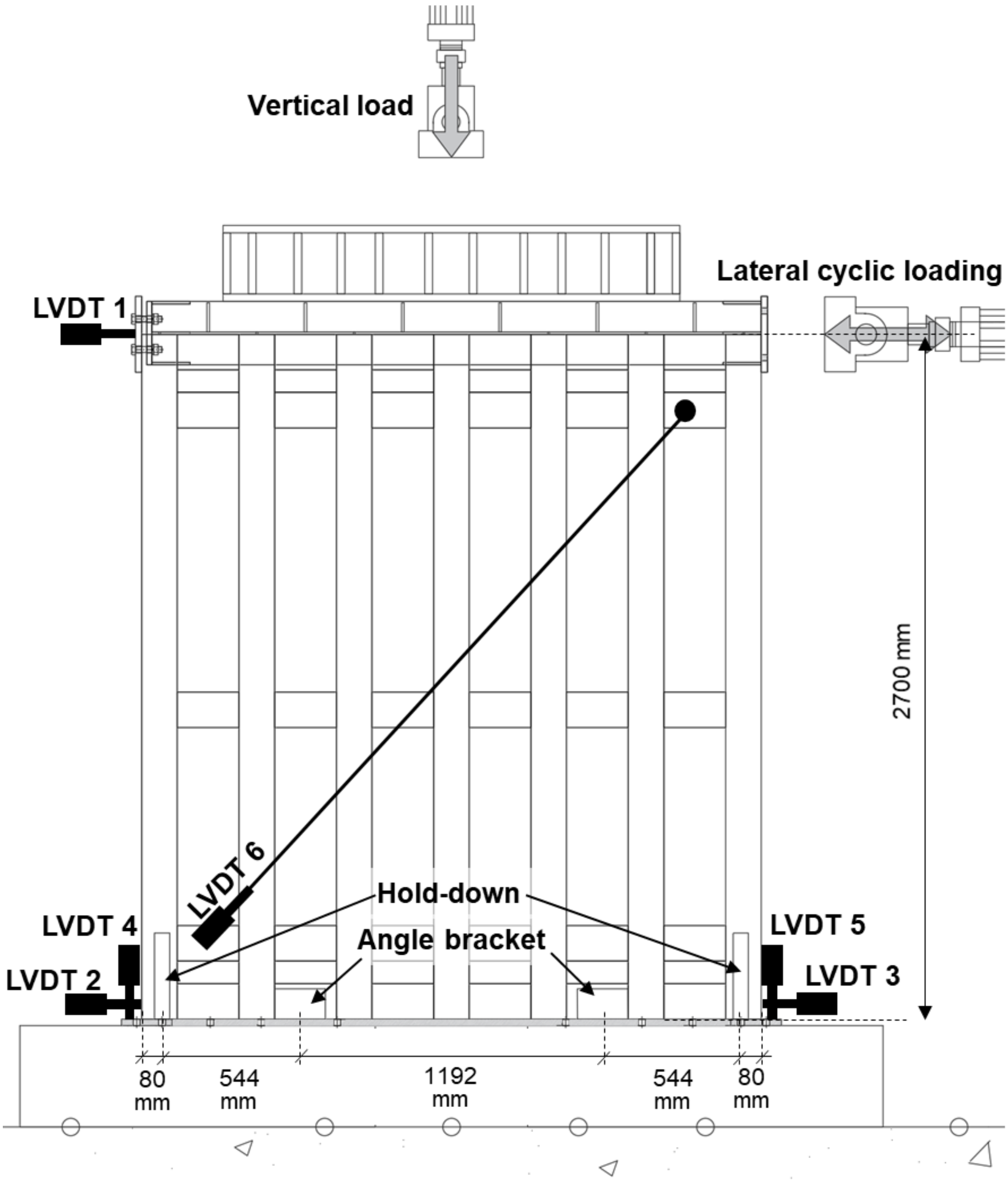


Fig. 4. Configuration of shear wall test

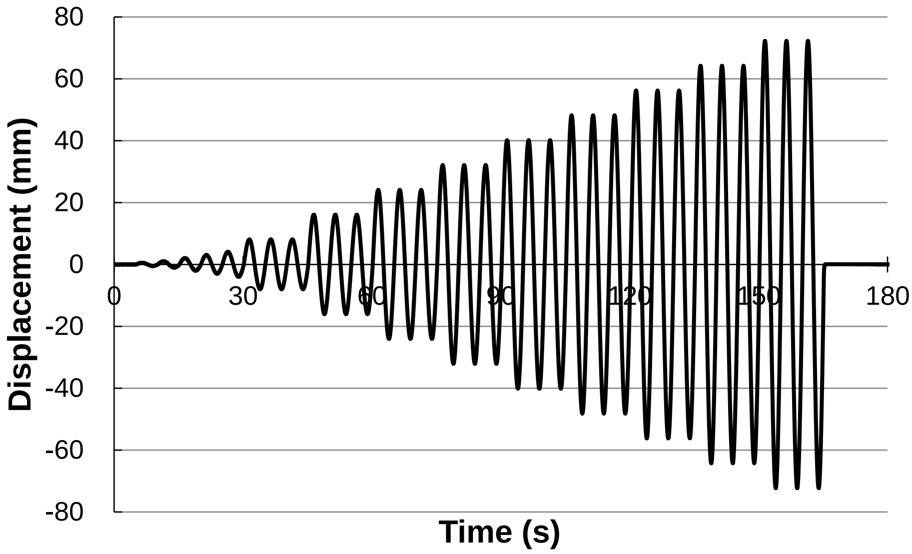


Fig. 5. Loading protocol (ISO 16670 (2003)) for shear wall test

RESULTS AND DISCUSSION

Light-Frame Timber Shear Wall

Failure mode

Figure 6 shows the failure mode in lateral behavior of the light-frame timber shear wall (No. 8). As displacement increased, the nails connecting the OSB sheathings to the timber studs at the upper edge of the wall gradually withdrew and the heads of the nails penetrated the OSB panels. Eventually, the OSB sheathings were separated from the timber studs, which is a common failure mode in light-frame shear walls (Liu *et al.* 2020). However, there was no damage to the connectors fixing the wall and the steel frame, until the end of the experiment. This shows that the lateral capacity of the light-frame timber shear wall was governed by the withdrawal resistance of the nails, and the metal products were strong enough to support the lateral capacity.

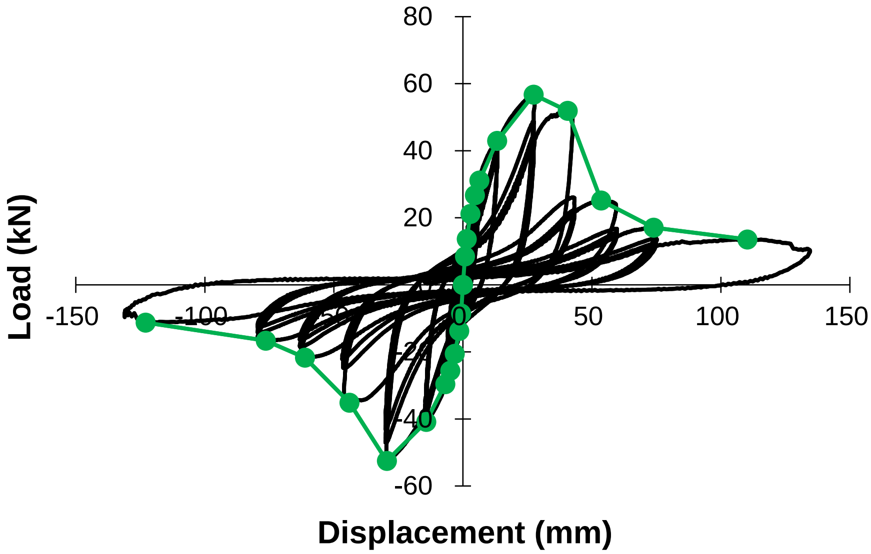
Fig. 6. Opening of the OSB sheathings due to the withdrawal of nails (No. 8)

Table 2. Mechanical Properties of Particleboard Shear Walls According to Load Protocol (ISO 16670) in ASTM E2126 (2009)

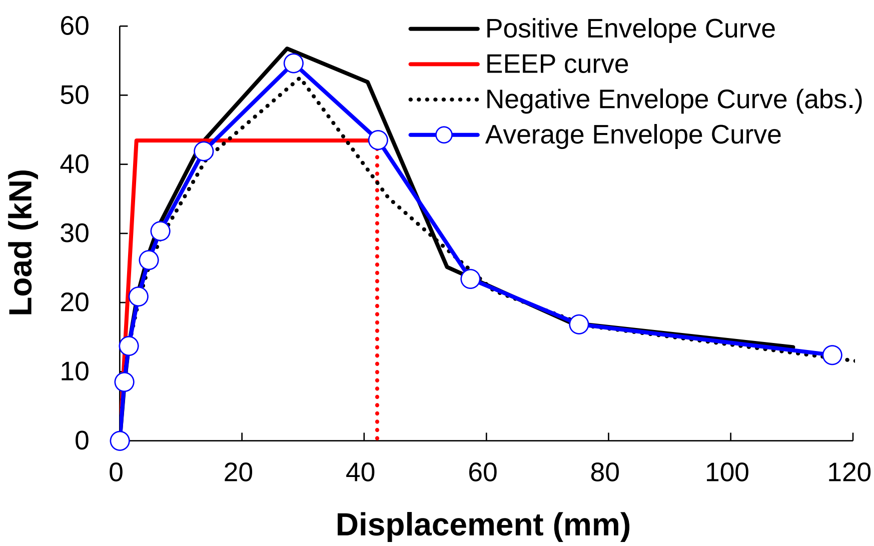
No.	Specimen ID	Strength				Stiffness			Ductility					
		v_{peak}[1] (kN/m)	P_{yield}[2] (kN)	P_{peak}[3] (kN)	P_u[4] (kN)	Ke[5] (kN/m)	G' at 0.4 P_{peak}[6] (kN/m)	G' at P_{peak}[7] (kN/m)	D_e[8] (mm)	D_{yield}[9] (mm)	D_{peak}[10] (mm)	D_u[11] (mm)	A[12] (kN.mm)	D[13]
No. 1	L(140)[14]-P[15]-2L[16]	74.8	152.7	179.6	143.7	19,078.6	21,463.4	9,417.5	3.8	8.0	21.5	26.3	4,418.0	3.3
No. 2	S(140)-P-2L	75.2	153.4	180.5	144.4	19,204.9	21,605.5	7,521.4	3.8	8.0	27.0	31.9	5,441.6	4.0
No. 3	L(89)-P-2L	73.4	149.7	176.2	140.9	16,477.0	18,536.7	9,024.3	4.3	9.1	22.0	26.7	4,264.2	2.9
No. 4	L(140)-P-3L	74.9	152.8	179.7	143.8	23,621.5	26,574.2	9,445.7	3.0	6.5	21.4	23.7	3,655.1	3.7
No. 5	L(140)-P-4L	75.6	154.2	181.4	145.1	20,523.2	23,088.6	9,756.7	3.5	7.5	20.9	34.0	4,963.3	4.5
No. 6	L(140)-N-2L	61.6	125.7	147.8	118.3	12,596.5	14,171.0	6,987.3	4.7	10.0	23.8	33.4	4,098.4	3.3
No. 7	L(89)-PW-2L	73.6	150.1	176.6	141.3	18,317.7	20,607.4	9,704.7	3.9	8.2	20.5	22.9	3,394.4	2.8
No. 8	Light-frame shear wall	22.8	43.4	54.6	43.7	15,816.8	17,794.0	2,161.0	1.4	2.7	28.4	42.1	1,770.7	15.3

1) shear strength: the maximum load (P_{peak}) per unit specimen length;
2) yield load calculated by equivalent energy elastic-plastic (EEEP) curve;
3) maximum load;
4) failure load;
5) elastic shear stiffness;
6) secant shear modulus at 0.4 P_{peak};
7) secant shear modulus at P_{peak};
8) displacement of the top edge of the specimen at 0.4 P_{peak};
9) yield displacement;
10) maximum displacement;
11) ultimate displacement;
12) the area under envelope curve from zero to ultimate displacement;
13) ductility ratio: the ratio of the ultimate displacement and the yield displacement of a specimen;
14) species and width of stud: L = larch, S = spruce, 140 = 140 mm width stud, 89 = 89 mm width stud;
15) connection method between timber stud and particleboard: P = polyurethane (PUR), N = nail, PW = PUR and wooden nail;
16) the number of particleboard layers: 2L = two layers, 3L = three layers, 4L = four layers

Table 2 shows the structural properties of the shear wall specimens. All of the basic properties recommended in ASTM E2126 (2009) are presented. The various properties for strength, stiffness, and ductility in Table 2 were derived from the average envelope curve of hysteretic curves (*e.g.*, Fig. 7(a)) and the equivalent energy elastic-plastic (EEEP) curve (*e.g.*, Fig. 7(b)) of each shear wall. Before failure occurred, the difference between the positive and negative envelope curves of each specimen was not significant, and the average envelope curve could represent the specimen. The standard (ASTM E2126) also recommends using the average envelope curve to derive the basic performance of a shear wall. The detailed information is mentioned in ASTM E2126 (2009).



(a) Hysteresis curve and envelope curves



(b) Average envelope curve and energy elastic-plastic (EEEP) curve

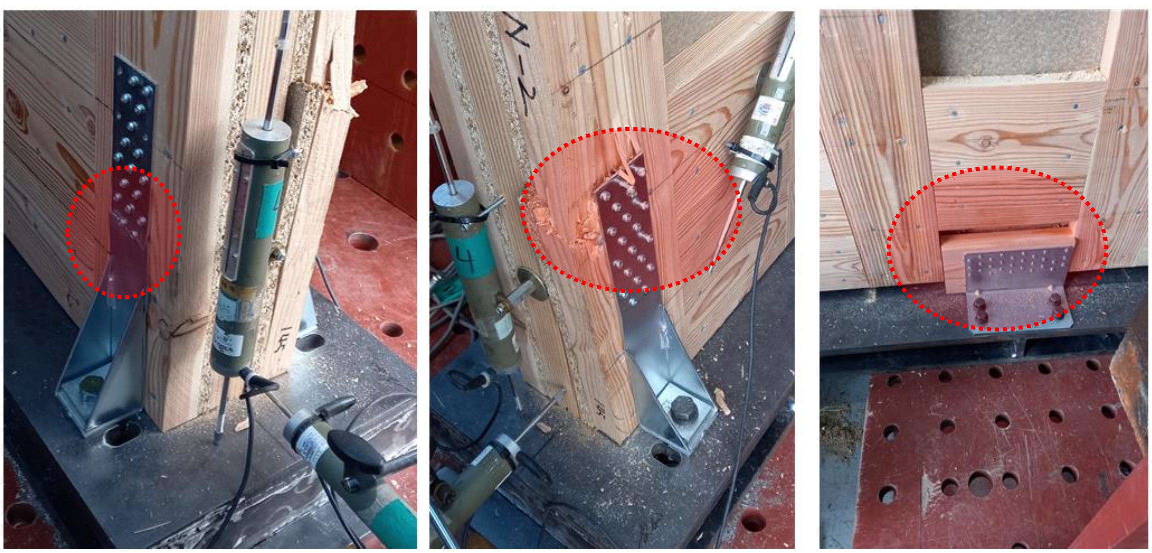
Fig. 7. Load-displacement curves of a light-frame timber shear wall (No. 8)

The structural performance of a timber shear wall is determined by the shear wall panel and the metal connectors fixing the shear wall panel and floor (Pang *et al.* 2021). In the lateral design of structures, the ultimate limit state (ULS) design is governed by the shear strength of the shear wall, and the serviceability limit-state (SLS) design is governed by the shear stiffness of the shear wall. Under the conditions of the metal connectors used in this study, the main structural properties of the light-frame timber shear wall (No. 8) were 22.8 kN/m (shear strength) and 17,794 kN/m (elastic shear stiffness).

Nailed Particleboard Shear Wall

Failure mode

Figure 8 shows the failure modes in the lateral behavior of a particleboard shear wall manufactured by nailing particleboards and timber studs (No. 6). Three failure modes were observed. At first, a hold-down at the bottom corner of the wall was torn out by the up-lift of the shear wall. Second, a timber stud failed at the top of the hold-down due to the up-lift load in the timber stud and the nail resistance fixed to the hold-downs. Third, a timber block connected with an angle bracket was fall out by the up-lift load of the shear wall and the resistance of the angle bracket. In other words, all failures occurred around the metal products (hold-down and angle bracket) connecting the shear wall specimen and the steel frame. No other damage was observed.



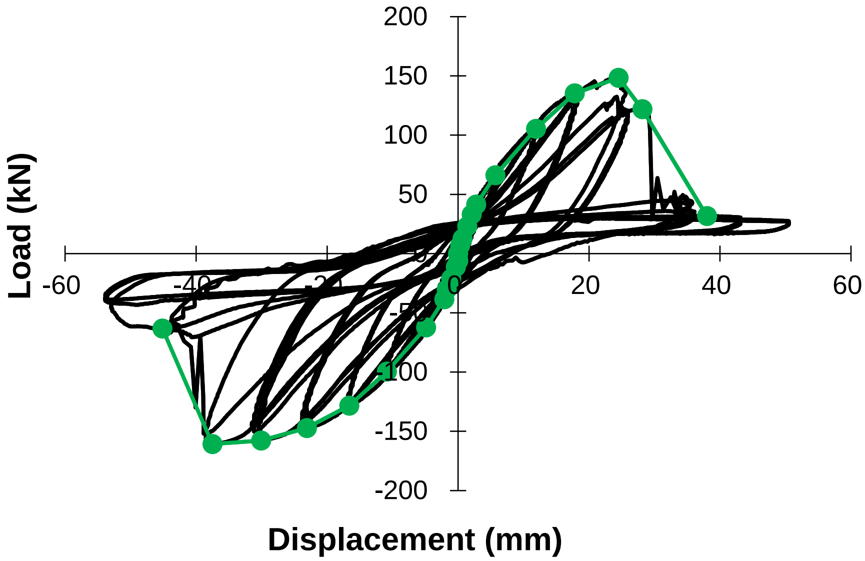
(a) Tensile failure of hold-down **(b)** Failure of timber stud **(c)** Falling of timber block

Fig. 8 Failure modes of a nailed particleboard shear wall (No. 6)

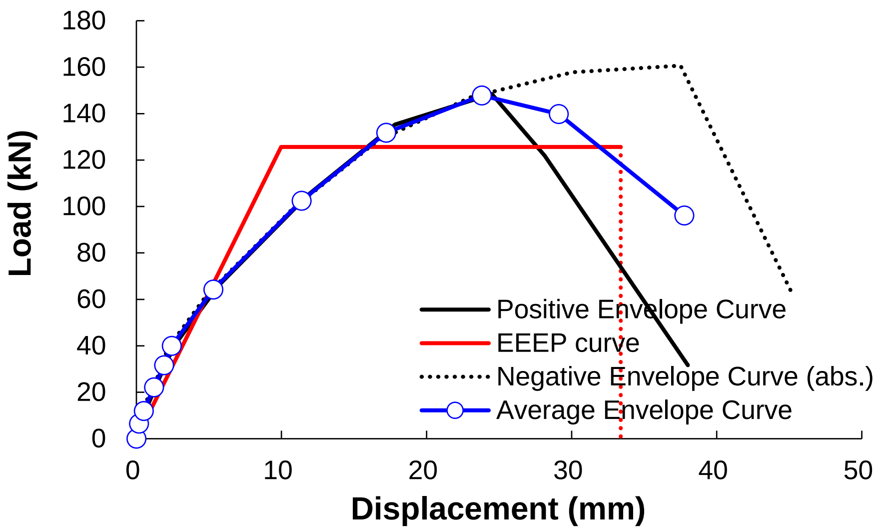
Figure 9 shows the envelope curves and an EEEP curve of the nailed particleboard shear wall. The shear strength was 22.8 kN/m, which was 2.7 times higher than the light-frame shear wall (No. 8). This is because the shear strength of the nailed particleboard shear wall was determined by the tensile strength of the steel and the failure of the stud, but the shear strength of the light-frame shear wall was determined by the withdrawal resistance of nails between the OSB sheathings and the timber studs.

The elastic shear stiffness of the nailed particleboard shear wall was approximately 0.8 times of the light-frame shear wall (No. 8). This indicates that the specimen failed in the metal products (hold-down) and its shear strength was higher than that of the light-frame shear wall. However, the deformation of nails fixing the particleboards and the timber studs was as large as the deformation of nails fixing the OSB sheathings and timber studs in the light-frame shear wall (No. 8).

When comparing Figs. 9(b) and 7(b), there is a remarkable difference. The system with the nailed particleboard shear wall showed essentially zero difference between the positive and negative envelope curves for displacements up to about 25 mm. At about 25 mm displacement, failure occurred at the connection, and the positive envelope curve was rapidly dropped. Thus, the zero difference between the positive and negative envelope curves shows that the shear wall behaved very symmetrically, and the large gap between the positive and negative envelopes shows the symmetric shear wall was unbalanced due to the failure.



(a) Hysteresis curve and envelope curves



(b) Average envelope curve and EEEP curve

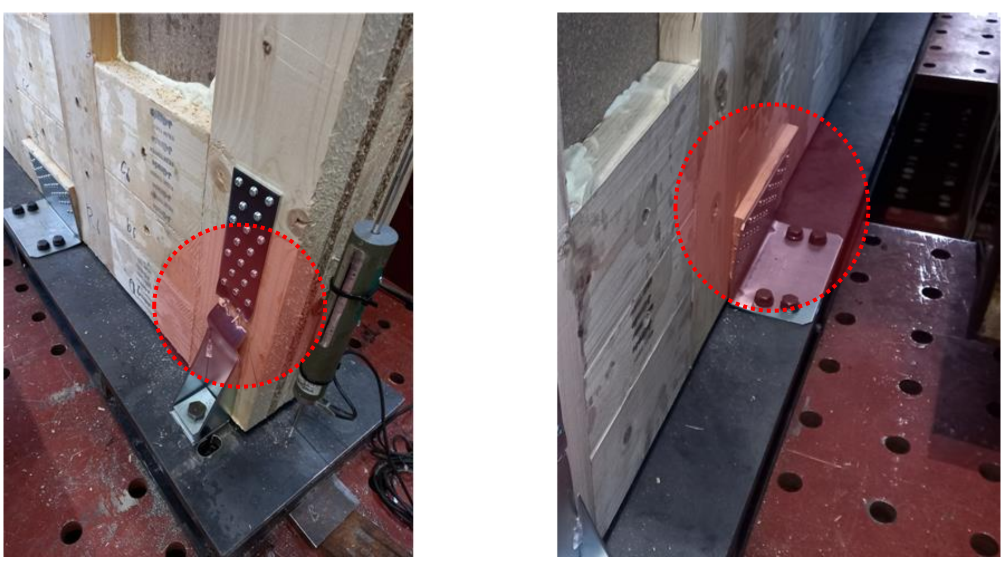
Fig. 9. Load-displacement curves of a nailed particleboard shear wall (No. 6)

Glued Particleboard Shear Walls

Failure modes

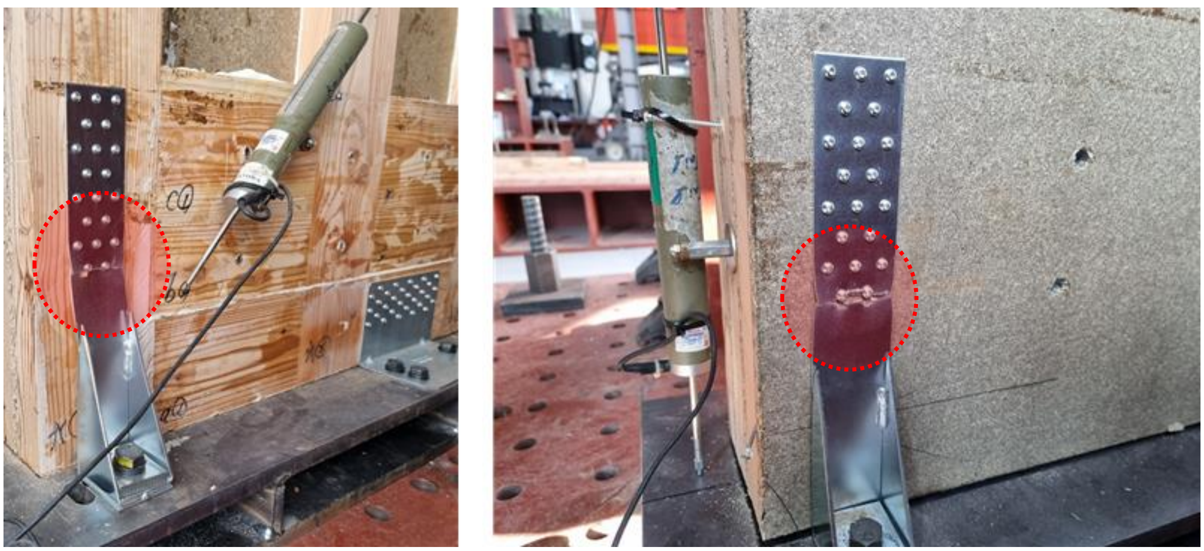
Figure 10 shows the failure modes in lateral behavior of a particleboard shear wall manufactured by gluing the particleboards and timber studs (No. 1 through No. 5 and No. 7). Two failure modes were observed. At first, the hold-downs at the bottom corners of the wall were torn out in all specimens. Second, a timber block connected with an angle bracket fell out only in No. 1 and No. 2 specimens, as did the nailed particleboard shear wall (No. 6). In No. 3, the width of timber studs was 89 mm, which was smaller than the other specimens. The installation position of the angle bracket was the same for all specimens, and a part of the angle bracket was fixed to the timber studs of No. 3. Thus, the tensile force acting on the angle bracket was passed to the stud and the timber block did not fall out. In No. 4 and No. 5, the particleboards were added to the surface and it prevented the wood block from falling out.

(a) Tensile failure of hold-down and falling of timber block (No. 1 _ L(140)-P-2L)

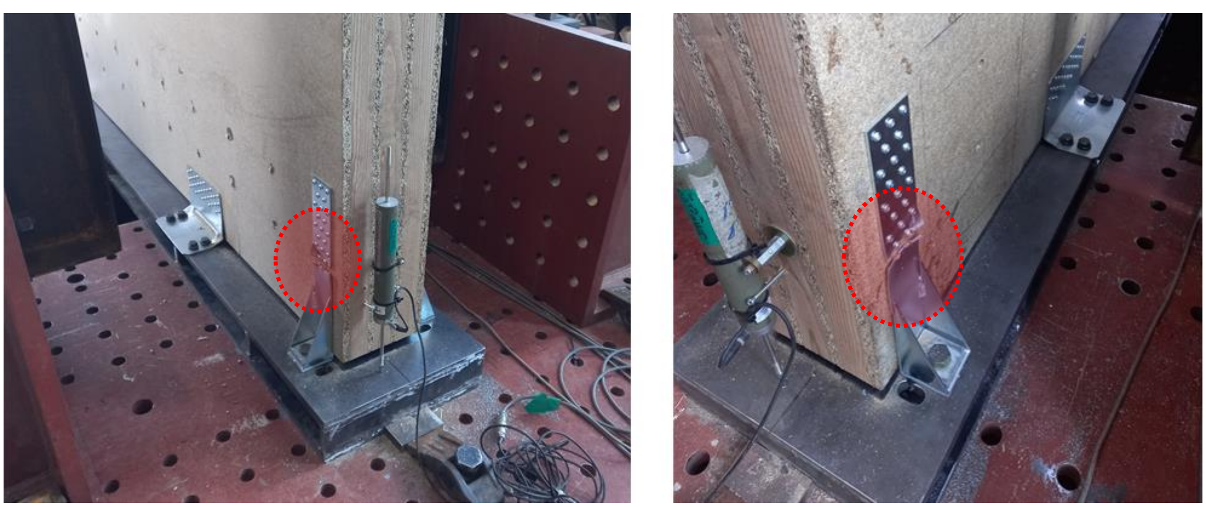


(b) Tensile failure of hold-down and falling of timber block (No. 2 _ S(140)-P-2L)

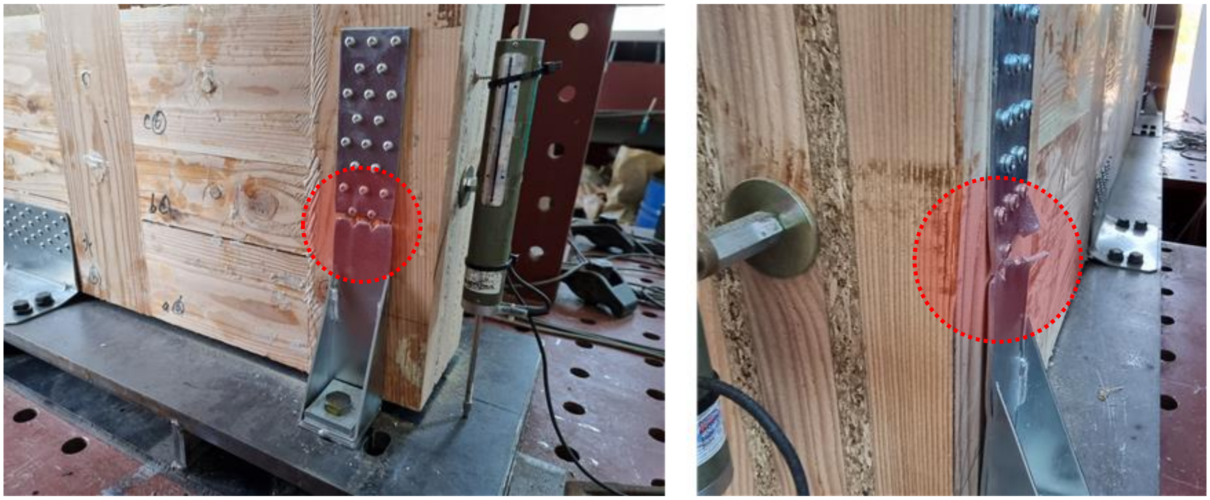
(c) Tensile failure of hold-down (No. 3 _ L(89)-P-2L)



(d) Tensile failure of hold-down (No. 4 _ L(140)-P-3L)



(e) Tensile failure of hold-down (No. 5 _ L(140)-P-4L)



(f) Tensile failure of hold-down (No. 7 _ L(89)-PW-2L)

Fig. 10. Failure modes of the glued particleboard shear walls

In No. 7, the timber blocks and particleboards were glued and reinforced with wooden nails. Thus, it seems that the wooden nails increased the glue and pull-out resistance of the timber blocks. No damage was observed other than the failures described at the metal connections. This indicates that the structural behavior of the tested shear walls was governed by the structural behavior of metal connectors like CLT shear walls (Innovations 2014; Germano *et al.* 2015).

This study is an experimental result for a short-term load. The falling of timber blocks due to localized damage of particleboard can reduce the long-term performance of the shear wall. Therefore, further research on the performance degradation of particleboard is needed in future work.

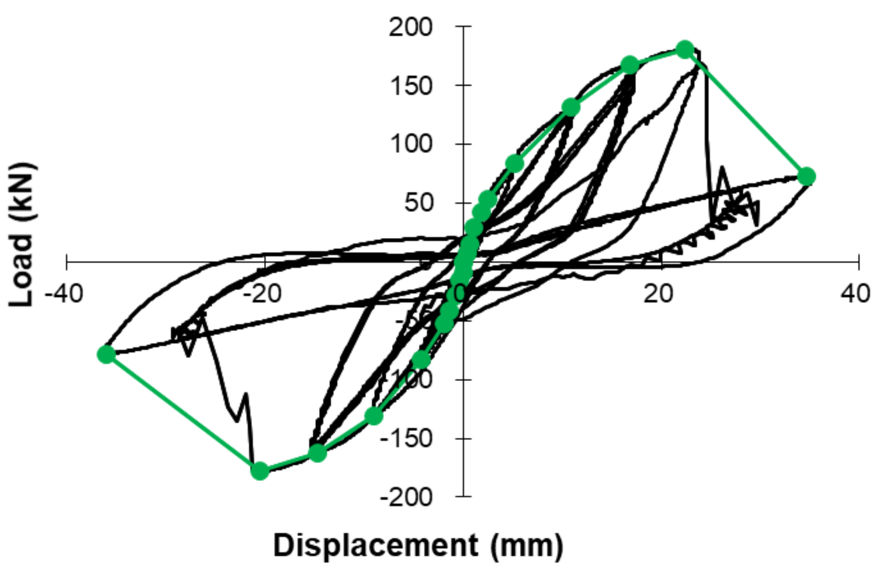
Figure 11 shows the envelope curves and an EEEP curves of the glued particleboard shear walls. Figure 12 shows the comparisons of the shear strength and stiffness of all tested specimens. There was no difference in shear strength depending on the stud size, species, and the number of particleboards (Fig. 12(a)). This was because the shear strength of the glued particleboard shear walls was determined by the tensile resistance of the hold-down. Thus, the quality of the gluing between particleboards and timber studs was sufficient to withstand the lateral load carrying capacity of the shear walls up to the failure of the hold-down, which means that the tested shear walls can be designed in the same way as the CLT shear wall.

The shear strength of the glued particleboard shear specimens was 73.4 to 75.6 kN/m, and 3.2 times higher than the light-frame shear wall (No. 8). These values were also higher than the shear strength of CLT shear walls reported by the experimental test. In the *CLT Handbook* (FPInnovations 2013), the highest shear strength of CLT shear walls was 57.2 kN/m, which is about 17 kN/m lower than that of the glued particleboard shear walls. Shi *et al.* (2022) investigated the lateral resistance of CLT shear walls with the same hold-down used in this study, the measured shear strength was 67.0 to 81.3 kN/m. The shear strength depends on the configuration of the shear wall panel and metal connectors. Nevertheless, the results of this study clearly show that it is possible to manufacture a particleboard shear wall as strong as CLT shear walls.

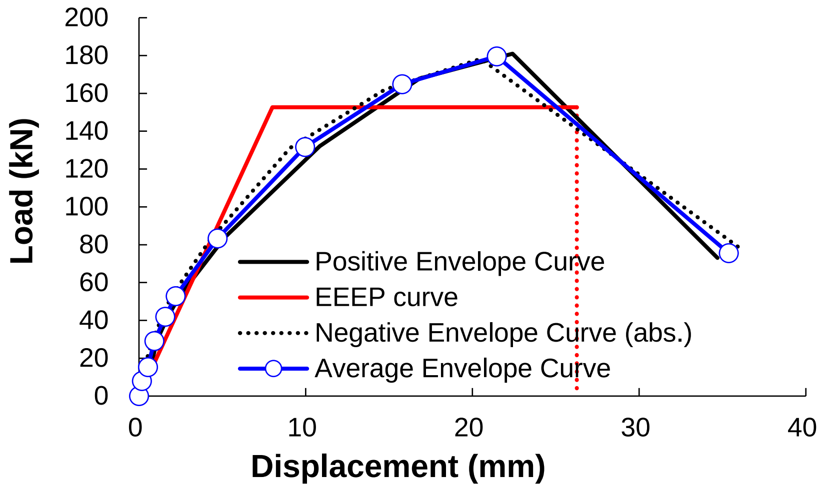
For the shear stiffness (Fig. 12(b)), the elastic shear stiffness of the No. 1 shear wall (timber stud: larch species, average value: 19,078 kN/m) was similar to that of the No. 2 shear wall (timber stud: spruce species, average value: 19,204 kN/m). This shows that the deformation of the glued particleboard shear wall was governed by the shear stiffness of the particleboard rather than the species of timber studs.

The elastic shear stiffness of the No. 3 shear wall (width of timber stud: 89 mm, average value: 16,477 kN/m) was 0.86 times of that of the No. 1 shear wall (width of timber stud: 140 mm). However, the elastic shear stiffness of the No. 7 shear wall (width of timber stud: 89 mm, average value: 18,317 kN/m), in which the No. 3 shear wall was reinforced with wooden nails, was 0.96 times that of the No. 1 shear wall (width of timber stud: 140 mm). This shows that the deformation of the glued particleboard shear walls was affected by the size of vertical timber studs because of the reduction of glue area. The reduced glue area made the shear resistance between particleboards and timber studs decrease, but the decreased shear resistance was reinforced by the wooden nails.

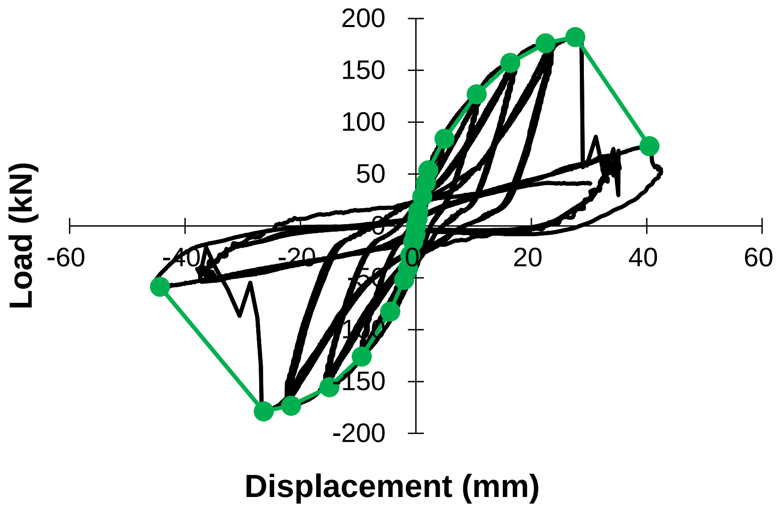
The elastic shear stiffness of the No. 4 shear wall (3 layers of particleboards, average value: 23,621 kN/m) and the No. 5 shear wall (4 layers of particleboards, average value: 20,523 kN/m) was 1.24 and 1.08 times higher than that of the No. 1 shear wall (2 layers of particleboards), respectively. This shows that the particleboard affects the increase in the stiffness of the shear wall; however, the shear stiffness did not increase proportionally with the increase in the number of particleboards. The shear stiffness is governed by the behavior of metal connectors and the bending behavior of the shear wall panel (Ceccotti *et al.* 2013; Zhang *et al.* 2021). The CLT panels in the shear wall are assumed to be a rigid body. The same metal connectors were used for all shear wall specimens in this study. Therefore, particleboard shear wall panels of No. 3 and No. 4 seem to have rigid body behavior under this experimental condition. Additionally, for the same reason, the difference in shear stiffness between the particleboard shear walls and the light-frame shear wall was not as large as that in the shear strength.



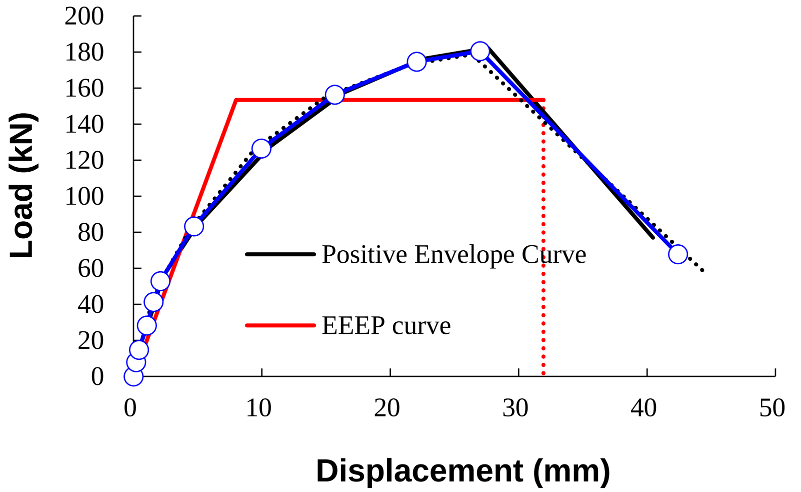
(a) Hysteresis curve and envelope curves (No. 1)



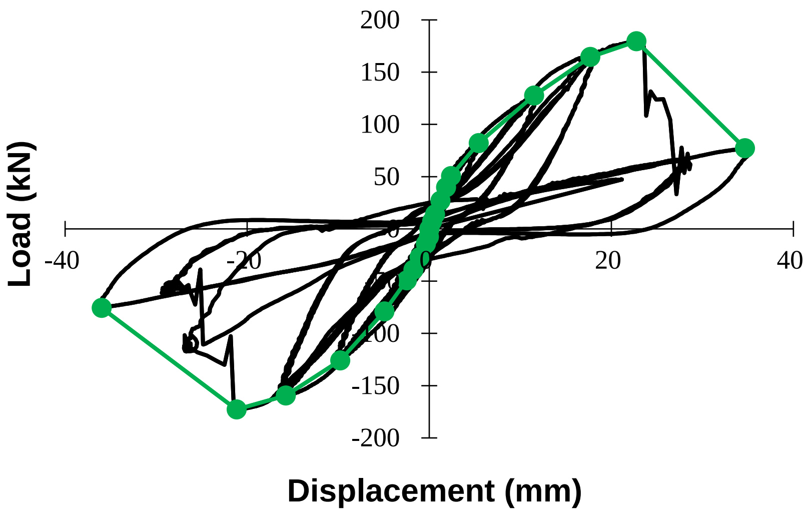
(b) Average envelope curve and EEEP curve (No. 1)



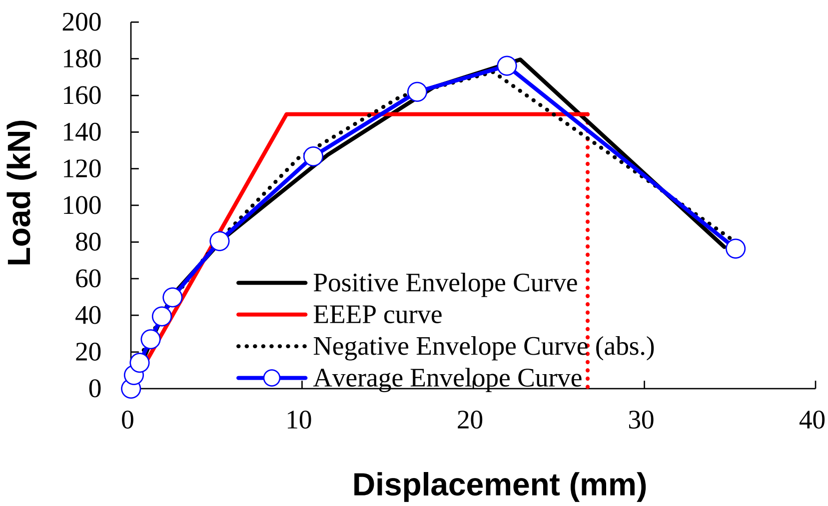
(c) Hysteresis curve and envelope curves (No. 2)



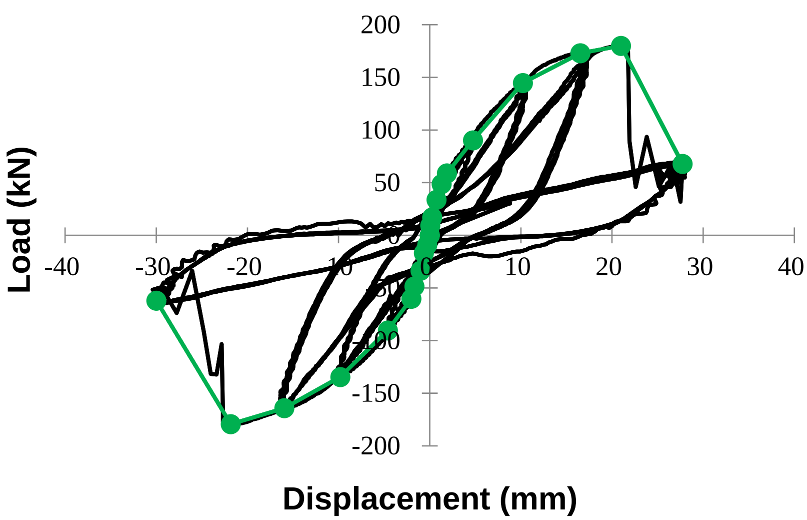
(d) Average envelope curve and EEEP curve (No. 2)



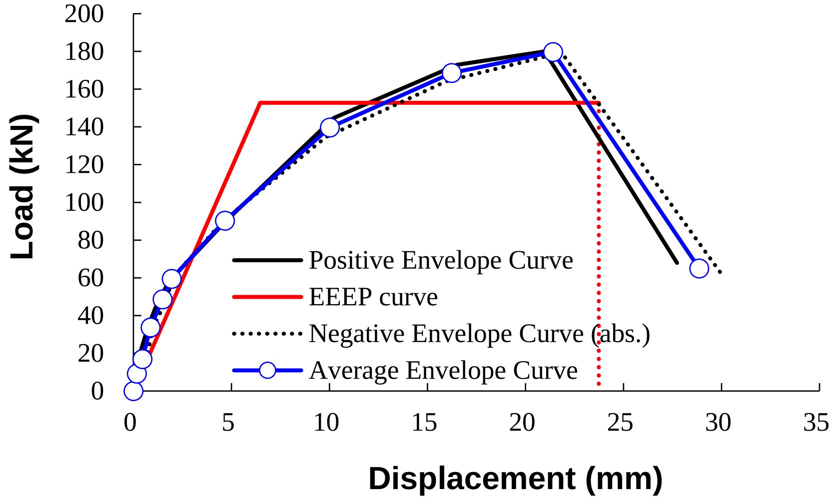
(e) Hysteresis curve and envelope curves (No. 3)



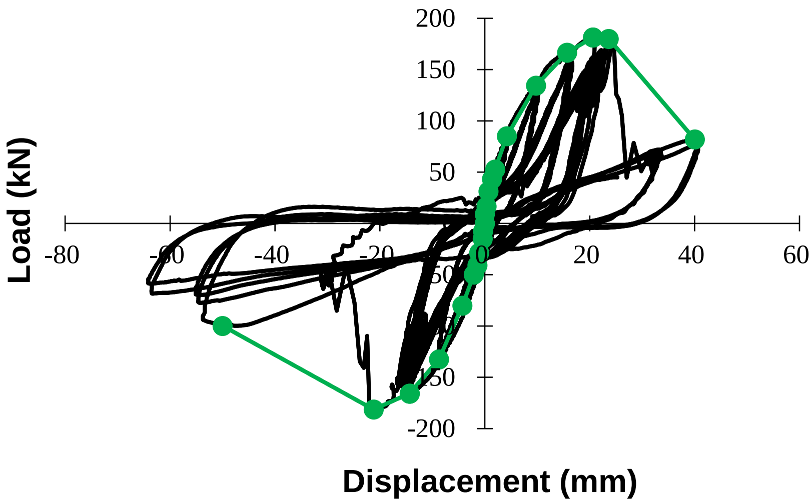
(f) Average envelope curve and EEEP curve (No. 3)



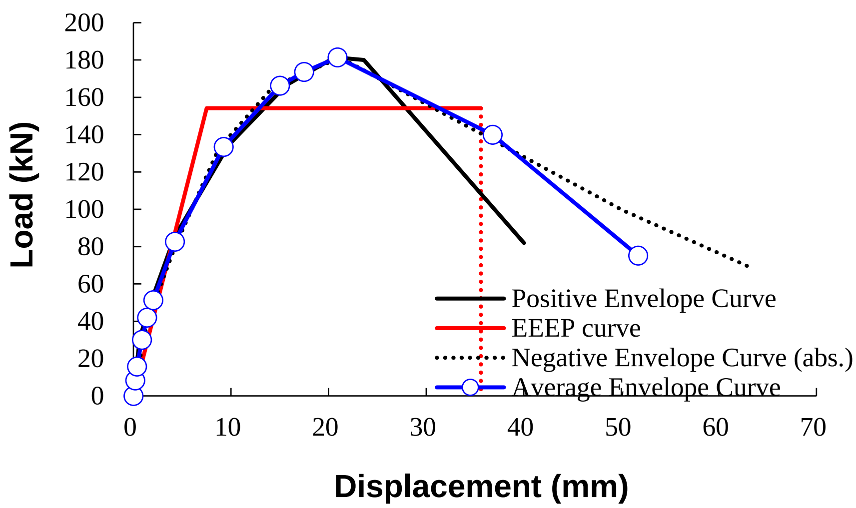
(g) Hysteresis curve and envelope curves (No. 4)



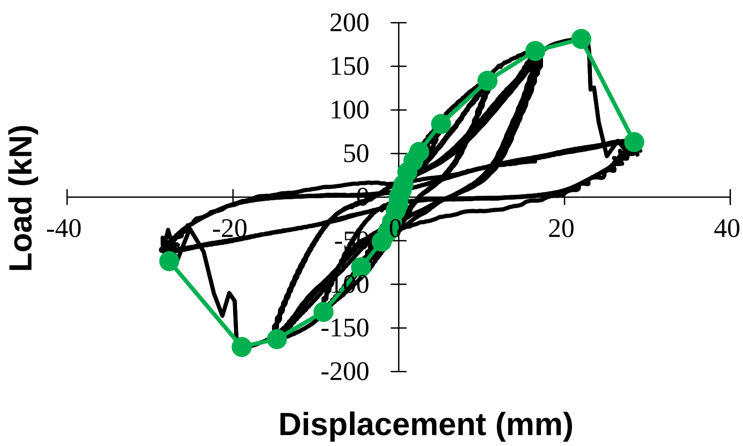
(h) Average envelope curve and EEEP curve (No. 4)



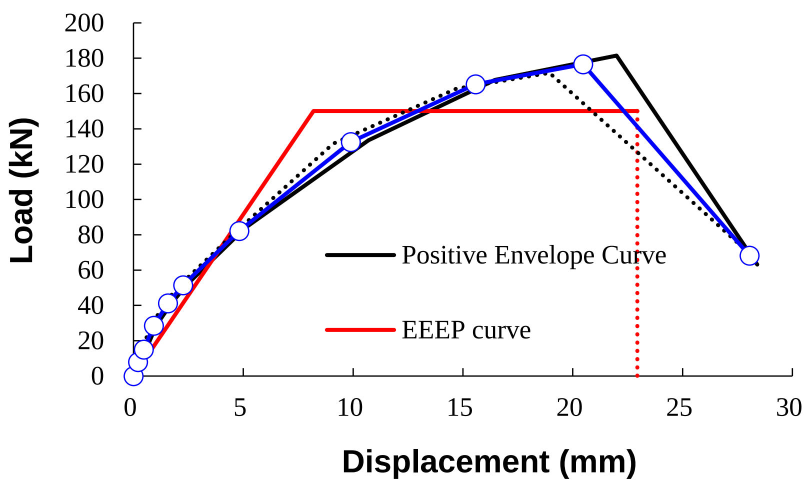
(i) Hysteresis curve and envelope curves (No. 5)



(j) Average envelope curve and EEEP curve (No. 5)

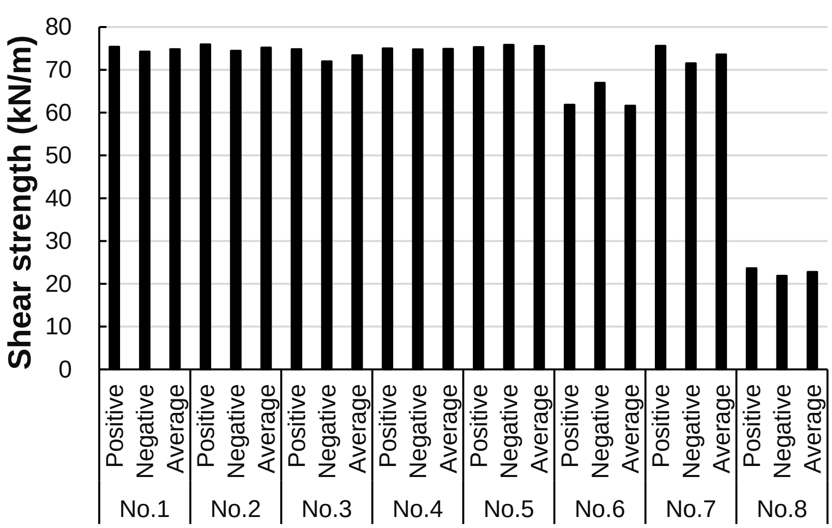


(k) Hysteresis curve and envelope curves (No. 7)

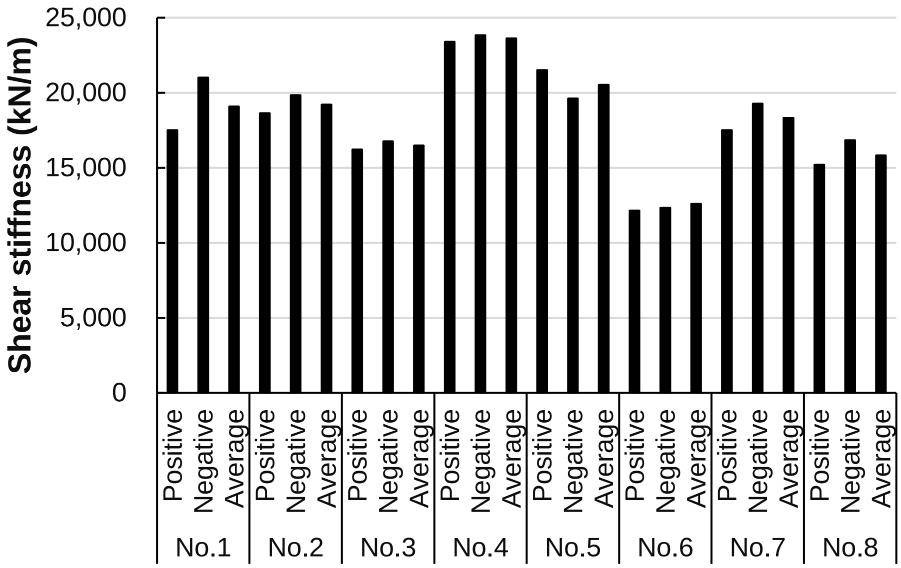


(l) Average envelope curve and EEEP curve (No. 7)

Fig. 11. Load-displacement curves of a glued particleboard shear wall



(a) Shear strength



(b) Elastic shear stiffness

Fig. 12. Comparisons of shear strength and stiffness of tested shear walls
(Note. Details of the test specimens are in Table 1 and Table 2. No.1: L(140)-P-2L; No.2: S(140)-P-2L; No.3: L(89)-P-2L; No.4: L(140)-P-3L; No.5: L(140)-P-4L; No.6: L(140)-N-2L; No.7: L(89)-PW-2L; No.8: Light-frame shear wall)

CONCLUSIONS

An experimental study was conducted on the lateral load capacity of particleboards shear walls under different wood species, the size of the timber studs, the number of particleboards, and whether the structure was held together by gluing or by nails. The main findings were as follows.

1. The shear strength of the glued particleboard shear walls was 73.4 to 75.6 kN/m. The capacities were approximately 3.2 times higher than that of the typical light-frame shear wall and higher than the experimental data of the CLT wall in the CLT handbook.
2. All glued particleboard shear walls failed at the hold-down and angle bracket, and there was no damage at the glue layer between particleboard layers and timber studs. This shows that the glue layers sufficiently supported the in-plane load between particleboard and timber studs up to the maximum tensile strength of hold-down, and the lateral capacities of the particleboard shear walls were greatly affected by the capacity of the metal connectors like the CLT shear walls.
3. A shear strength of a nailed particleboard shear wall was approximately 20% lower than that of the glued particleboard shear walls. However, the shear strength of glued particleboard shear walls with different combinations, species, stud sizes, and number of particleboards was not noticeably different. For shear stiffness, the difference between the particleboard shear walls and the light-frame shear wall was not as large as that in the shear strength. The same metal connectors were used for all shear wall specimens. The shear stiffness was determined in the elastic state, not in failure.

Therefore, this indicates that shear stiffness was also mainly governed by the behavior of metal connectors.

ACKNOWLEDGEMENTS

This study was conducted with the support of the R&D Program for Forest Science Technology (Project No. 2020222A00-2222-AC02), provided by the Korea Forest Service. This project was funded by the Korea Forest Service (Korea Forestry Promotion Institute).

Competing Interests

The authors declare they have no competing interest.

Authors' Contributions

Sung-Jun Pang designed and analyzed the experimental test and wrote this manuscript. Han Shik Lee designed and manufactured the test specimens. Jung-Kwon Oh managed this research project and approved the final manuscript.

REFERENCES CITED

Asdrubali, F., Ferracuti, B., Lombardi, L., Guattari, C., Evangelisti, L., and Grazieschi, G. (2017). "A review of structural, thermo-physical, acoustical, and environmental properties of wooden materials for building applications," *Building and Environment* 114, 307-332. DOI: 10.1016/j.buildenv.2016.12.033

ASTM E2126 (2009). "Standard test methods for cyclic (reversed) load test for shear resistance of vertical elements of the lateral force resisting systems for buildings," ASTM International, West Conshohocken, PA, USA.

ASTM E564-06 (2018). "Standard practice for static load test for shear resistance of framed walls for buildings," ASTM International, West Conshohocken, PA, USA.

Bekhta, P., Korkut, S., and Hiziroglu, S. (2013). "Effect of pretreatment of raw material on properties of particleboard panels made from wheat straw," *BioResources* 8(3), 4766-4774

FPInnovations (2013). *CLT Handbook*, FPInnovations, Montreal, Canada.

Ceccotti, A., Sandhaas, C., Okabe, M., Yasumura, M., Minowa, C., and Kawai, N. (2013). "SOFIE project - 3D shaking table test on a seven-storey full-scale cross-laminated timber building," *Earthquake Engineering and Structural Dynamics* 42(13), 2003-2021. DOI: 10.1002/eqe.2309

De Almeida, A. C., De Araujo, V. A., Morales, E. A. M., Gava, M., Munis, R. A., Garcia, J. N., and Cortez-Barbosa, J. (2017). "Wood-bamboo particleboard: Mechanical properties," *BioResources* 12(4), 7784-7792. DOI: 10.15376/biores.12.4.7784-7792

Gerilla, G. P., Teknomo, K., and Hokao, K. (2007). "An environmental assessment of wood and steel reinforced concrete housing construction," *Building and Environment* 42(7), 2778-2784. DOI: 10.1016/j.buildenv.2006.07.021

Germano, F., Metelli, G., and Giuriani, E. (2015). "Experimental results on the role of sheathing-to-frame and base connections of a European timber framed shear wall," *Construction and Building Materials* 80, 315-328. DOI: 10.1016/j.conbuildmat.2015.01.076

Hafner, A., and Schäfer, S. (2018). "Environmental aspects of material efficiency *versus* carbon storage in timber buildings," *European Journal of Wood and Wood Products* 76(3), 1045-1059. DOI: 10.1007/s00107-017-1273-9

Hashim, R., Wan Nadhari, W. N. A., Sulaiman, O., Sato, M., Hiziroglu, S., Kawamura, F., Sugimoto, T., Seng, T. G., and Tanaka, R. (2012). "Properties of binderless particleboard panels manufactured from oil palm biomass," *BioResources* 7(1), 1352-1365.

ISO 16670 (2003). "Timber structure-joints made with mechanical fasters–Quasi-static reversed cyclic test method," International Organization for Standardization, Geneva, Switzerland.

Li, J., Rismanchi, B., and Ngo, T. (2019). "Feasibility study to estimate the environmental benefits of utilising timber to construct high-rise buildings in Australia," *Building and Environment* 147, 108-120. DOI: 10.1016/j.buildenv.2018.09.052

Liu, Y., Gao, Z., Ma, H., Gong, M., and Wang, H. (2020). "Racking performance of poplar laminated veneer lumber frames and frame-shear hybrid walls," *BioResources* 16(1), 354-371. DOI: 10.15376/biores.16.1.354-371

NIFoS notification No. 2020-3 (2020). "Specifications and quality standards of wood products - structural lumber and plywood," National Institute of Forest Science, Seoul, Republic of Korea.

Pang, S.-J., Ahn, K.-S., Kang, S. G., and Oh, J.-K. (2021). "Lateral resistance of mass timber shear wall connected by withdrawal-type connectors," *Journal of Wood Science* 67(1), article no. 34. DOI: 10.1186/s10086-021-01967-7

Petersen Raymer, A. K. (2006). "A comparison of avoided greenhouse gas emissions when using different kinds of wood energy," *Biomass and Bioenergy* 30(7), 605-617. DOI: 10.1016/j.biombioe.2006.01.009

Polastri, A., Izzi, M., Pozza, L., Loss, C., and Smith, I. (2019). "Seismic analysis of multi-storey timber buildings braced with a CLT core and perimeter shear-walls," *Bulletin of Earthquake Engineering* 17(2), 1009-1028. DOI: 10.1007/s10518-018-0467-9

Resch, E., Andresen, I., Cherubini, F., and Brattebø, H. (2021). "Estimating dynamic climate change effects of material use in buildings—Timing, uncertainty, and emission sources," *Building and Environment* 187, article ID 107399. DOI: 10.1016/j.buildenv.2020.107399

Röck, M., Saade, M. R. M., Balouktsi, M., Rasmussen, F. N., Birgisdottir, H., Frischknecht, R., Habert, G., Lützkendorf, T., and Passer, A. (2020). "Embodied GHG emissions of buildings – The hidden challenge for effective climate change mitigation," *Applied Energy* 258, article ID 114107. DOI: 10.1016/j.apenergy.2019.114107

Sandanayake, M., Lokuge, W., Zhang, G., Setunge, S., and Thushar, Q. (2018). "Greenhouse gas emissions during timber and concrete building construction —A scenario based comparative case study," *Sustainable Cities and Society* 38, 91-97. DOI: 10.1016/j.scs.2017.12.017

Shi, X., Yue, K., Jiao, X., Zhang, Z., and Li, Z. (2022). "Experimental investigation into lateral performance of cross-laminated timber shear walls made from fast-growing poplar wood," *Wood Material Science & Engineering* (Online). DOI: 10.1080/17480272.2022.2121659

Stazi, F., Serpilli, M., Maracchini, G., and Pavone, A. (2019). "An experimental and numerical study on CLT panels used as infill shear walls for RC buildings retrofit," *Construction and Building Materials* 211, 605-616. DOI: 10.1016/j.conbuildmat.2019.03.196

Yan, H., Shen, Q., Fan, L. C. H., Wang, Y., and Zhang, L. (2010). "Greenhouse gas emissions in building construction: A case study of One Peking in Hong Kong," *Building and Environment* 45(4), 949-955. DOI: 10.1016/j.buildenv.2009.09.014

Yue, K., Liang, B., Liu, J., Li, M., Pu, Y., Lu, W., Han, Z., and Li, Z. (2022). "Fire resistance of light wood frame walls sheathed with innovative gypsum-particle composite: Experimental investigations," *Journal of Building Engineering* 45, Article ID 103576. DOI: 10.1016/j.jobe.2021.103576

Zhang, D., Shen, L., Zhu, X., Zhang, S., and Gong, M. (2021). "The influence of the opening size on the shear performance of the cross-laminated timber (CLT) walls," *BioResources* 16(4), 7071-7085. DOI: 10.15376/biores.16.4.7071-7085

Article submitted: October 21, 2022; Peer review completed: November 29, 2022; Revised version received and accepted: December 8, 2022; Published: December 12, 2002.
DOI: 10.15376/biores.18.1.1072-1095