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ORIGINAL ARTICLE

Shear behavior of cross-laminated timber wall consisting of small panels

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Abstract A cross-laminated timber (CLT) wall plays the role of resisting shear stress induced by lateral forces as well as vertical load. Due to the press size, CLT panels have a limitation in size. To minimize the initial investment, some glulam manufactures wanted to make a shear wall element with small-size CLT panels and panel-to-panel connections and wanted to know whether the shear wall would have equivalent shear performance with the wall made of a single CLT panel. In this study, this was investigated by experiments and kinematic model analysis. Two shear walls made of small CLT panels were tested. The model showed a good agreement with test results in the envelope curve. Even though the shear walls were made of small panels, the global peak load did not decrease significantly compared with the wall made of a single CLT panel, but the global displacement showed a large increase. From this analysis, it was concluded that the shear wall can be designed with small CLT panels , but displacement should be designed carefully.

Keywords Cross-laminated timber · Shear performance of CLT wall · Panel-to-panel connection of CLT wall · Kinematic model

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Introduction

Recently, cross-laminated timber (CLT) has been spotlighted as a shear-resisting structural element in building. Especially in tall buildings, the building needs to resist heavy lateral force, such as wind and seismic load. Kuilen et al. [1] mentioned that CLT is a product extremely well suited for multi-story buildings.

In manufacturing the CLT panel, a press facility is required to press laminae with adhesives. The most typical press facility is a cold-press unit consisting of hydraulic actuators. As the size of the CLT panel increases, the cost of the facility increases dramatically because the required capacity of the hydraulic actuator would increase in proportion to the area of the panel. This indicates that there is limitation in the CLT panel size in terms of initial investment for CLT plant establishment. To avoid the high initial investment, some manufacturers make a shear wall element with small CLT panels (1.2 by 2.4 m). It would be less costly in terms of the initial facility investment. Also during transporting, the small-size panels would be free from road regulation of transportation. Also, it is easier to handle them during construction.

However, connections between panels are required to make a CLT shear wall. Ashtari et al. [2] reported that the in-plane shear behavior of the CLT floor diaphragm is primarily dependent on the properties of the connections and shear modulus of elasticity of CLT panels. Vessby et al. [3] reported that the strength and stiffness of the mechanical connection are weak. The CLT shear wall including panel-to-panel connections may be weaker than the same-size CLT wall of a single panel.

In CLT shear wall, various types of connections (brackets, single spline and lapped joint) and fasteners (nails, self-tapping screws, timber rivets) can be used, as well as various wall aspect ratios and various types of CLT panel (3 ply, 5 ply, species and grade). Due to this variety, many researchers have developed a model to predict the performance of the CLT panel (Okabe et al. [4], Oh et al. [5]). Also because there are very varied connections, several models to predict the shear performance of CLT shear wall connection have been developed. Filiatrault and Folz [6] applied a kinematic model for seismic design of wood frame building. FPInnovations and Binational Softwood Lumber Council [7] described a kinematic model, in which the performance of the CLT wall could be predicted by the properties of connection under the assumption that the CLT panel is a rigid body. Gavric et al. [8] developed an analytical model and analyzed the CLT wall made of two horizontally connected panels. Yasumura [9] formulated the CLT wall connected by horizontally connected panels and validated the formula. But the connection for vertically extending has not been investigated.

Vertically extending by connection can cause two problems. The first is wall buckling at the connection by vertical load above the wall, such as the upper story load and snow load. The second problem is the weak shear performance of the CLT wall by the connection. As a first step of the research on the small CLT panel (1.2 by 2.4 m) for structural use, the shear performance of the multiple-panel shear wall was investigated in this study.

The shear wall consisting of small panels (1.2 by 2.4 m) can fail by additional modes initiated at vertically extending (VE) or horizontally extending (HE) connections. By the kinematic approach, the formulae for the additional failure mode were obtained in this study. For the CLT shear wall consisting of small panels to have an equivalent shear capacity to a single large panel wall, the failure should not be at the HE and VE connection. Based on this requirement, the CLT shear wall was designed to fail by uplift force at the bracket by the kinematic formulae and experimentally investigated. Also, the influence of panel-to-panel connection on the behavior of shear wall was investigated by experimental and kinematic analysis.

Formulation of the kinematic model

Under the assumption that the CLT panel is a rigid body, FPInnovations and Binational Softwood Lumber Council [7] described a formula for the CLT shear wall without panel-to-panel connections as Mode A of Fig. 1. In this assumption, the global deformation (D) of the CLT wall is dependent on the property of the bracket.

But when using small panels to make a large shear wall, the panels should be vertically and horizontally connected by VE and HE connections. The connections can also cause the global failure of the CLT shear wall as well as bracket failure described in a previous research (FPInnovations and Binational Softwood Lumber Council [7]). Therefore, additional failure modes need to be formulated (Fig. 1). The shear capacity, F, of the failure mode C was formulated by Yasumura [9]. He experimentally validated the formulae of failure mode A and C. The shear capacity of failure mode B was formulated in this study. At the failure by the panel-to-panel connection, the global deformation (D) can be formulated as in Eqs. 3, 5 and 7 under the assumption of the rigid body.

For mode A: uplift failure at the bracket

$$D_{\mathrm{uplift},b} = \frac{H}{l_{b,t,1}} d_{b,t,1} = \frac{H}{l_{b,t,2}} d_{b,t,2} = \frac{H}{l_{b,t,i}} d_{b,t,i}, \tag{1}$$

$$F_{\mathrm{uplift},b}\left(D_{\mathrm{uplift},b}\right) = \sum_{i=1}^{n} \frac{l_{b,\mathrm{t},i}}{H} f_{b,t,i}\left(d_{b,t,i}\right) + \frac{L}{2H} G. \tag{2}$$

For mode B-1: uplift failure at VE wall-to-wall connection

$$D_{\mathrm{uplift},v} = \frac{h}{l_{v,t,1}} d_{v,t,1} = \frac{h}{l_{v,t,2}} d_{v,t,2} = \frac{h}{l_{v,t,i}} d_{v,t,i}, \tag{3}$$

$$F_{\mathrm{uplift},v}\left(D_{\mathrm{uplift},v}\right) = \sum_{i=1}^{n} \frac{l_{v,i}}{h} f_{v,t,i}\left(d_{v,t,i}\right) + \frac{L}{2h} G. \tag{4}$$

For mode B-2: shear failure at VE panel-to-panel connection

$$D_{\mathrm{shear},v} = d_{v,s,i}, \tag{5}$$

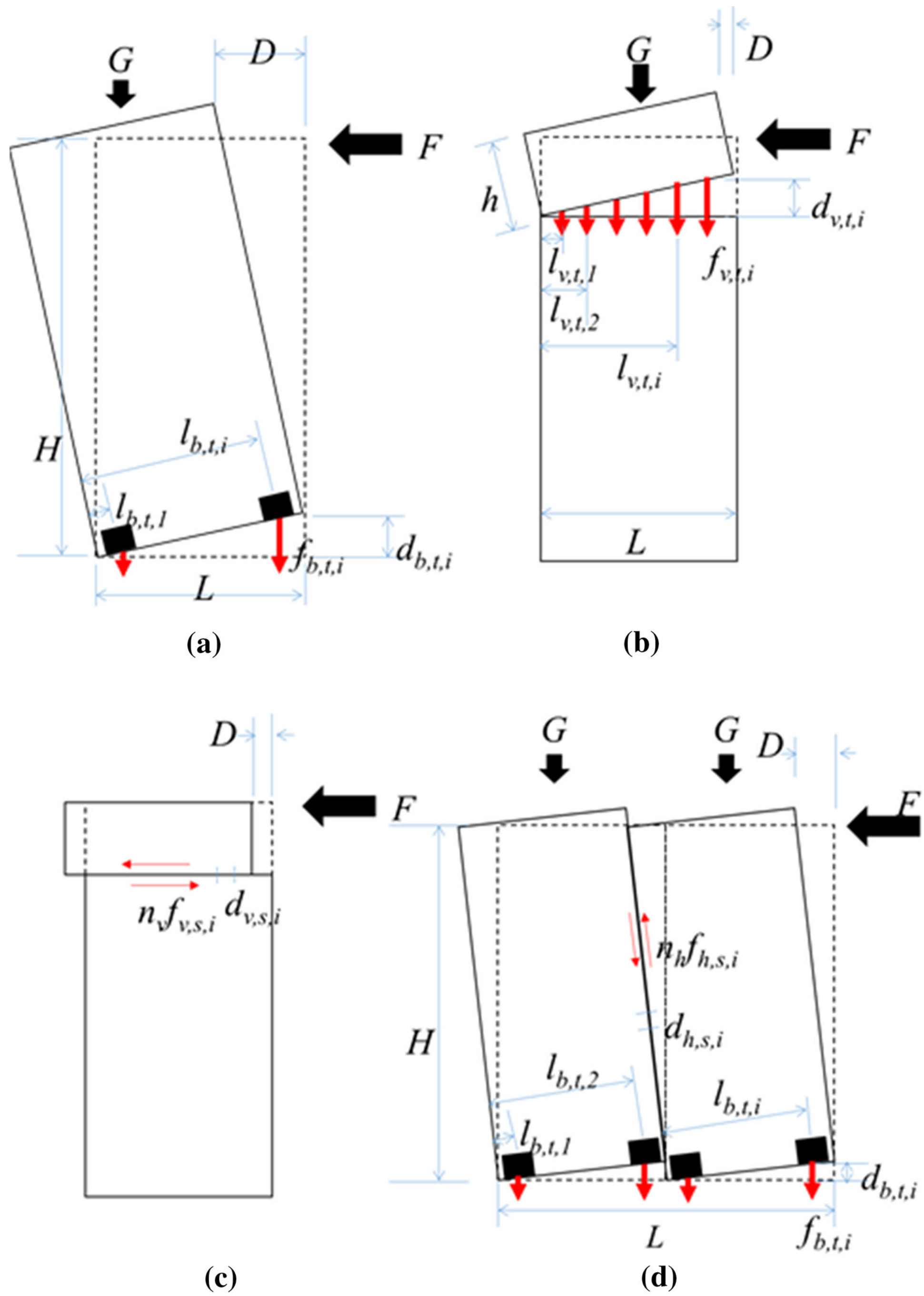
$$F_{\mathrm{shear},v}\left(D_{\mathrm{shear},v}\right) = n_v f_{v,s,i}\left(d_{v,s,i}\right). \tag{6}$$

For mode C: shear failure at HE panel-to-panel connection

$$D_{\mathrm{shear},h} = \frac{NHd_{h,s,i}}{L}, \tag{7}$$

$$F_{\mathrm{shear},h}\left(D_{\mathrm{shear},h}\right) = \frac{L}{2H} n_h f_{h,s,i}\left(d_{h,s,i}\right) + \sum_{i=1}^{n} \frac{l_{b,t,i}}{H} f_{b,t,i}\left(d_{b,t,i}\right) + \frac{L}{2H} G, \tag{8}$$

Fig. 1 Shear wall behavior according to failure mode. **a** Mode A: uplift failure at the bracket. **b** Mode B-1: uplift failure at the vertically extending panel-to-panel connection. **c** Mode B-2: shear failure at the vertically extending panel-to-panel connection. **d** Mode C: shear failure at the horizontally extending panel-to-panel connection



$$d_{h,s,i} = \frac{d_{b,t,1}L}{l_{b,t,1}} = \frac{d_{b,t,2}L}{l_{b,t,2}} = \cdots = \frac{d_{b,t,i}L}{l_{b,t,i}}, \tag{9}$$

where H is the height of the wall (mm), L the length of multiple-panel wall (mm), N the number of panels in a multiple-panel wall, G the gravity load acting on the top of a single panel by the upper floor (N), $F_{\gamma,\alpha}$ $(D_{\gamma,\alpha})$ the global force at $D_{\gamma,\alpha}$ mm global displacement at the failure mode caused by stress γ at connection α (N), $D_{\gamma,\alpha}$ the global displacement caused by the failure mode related to stress γ at the connection α (N), $f_{\alpha,\beta,i}(d_{\alpha,\beta,i})$ the resistance of the ith connector α at d_i mm displacement under stress β (N), $d_{\alpha,\beta,i}$ the displacement of the ith connector α under stress β (mm), n_α the number of screws at the connection α, $l_{\alpha,\beta,i}$ the distance from the center of the ith connection α to the center point of the turning by uplifting, α the type of connection (b bracket; h HE connection, v VE connection), β the type of stress (t tension/uplift; s shear) and γ the type of stress leading to failure (uplift, shear).

For each failure mode, the peak load can be calculated based on the peak load obtained at the experiments for the unit connection. The experiment for the unit connection should be carried out for each component of stress; uplift resistance of bracket, uplift resistance of VE connection, shear resistance of the VE connection and shear resistance of the HE connection. Based on the 4 peak loads of the unit connections, the global peak load can be calculated by the formulas for each failure mode.

Figure 2 shows an example for CLT wall with HE and VE connections. In mode A, the wall moves like a single panel wall. If the wall follows the mode A, the shear capacity would be the same as the wall made of a single panel. In mode B, the wall failure is preceded from the VE connection. In mode C, the wall failure is initiated by weak HE connection and the two wall parts turn independently as in Fig. 2d. It should be noticed that the center of turning by uplift is different between modes A and C; hence, the $l_{b,t,3}$ in mode A is different from mode C. The capacity of mode C is calculated by adding the capacity of two half-length walls (first term in Eq. 8) and additional capacity by HE connections (second term in Eq. 8). If there is no HE connection, the capacity of the wall would be the sum of the two half-length walls and would be smaller than the mode A. This means that the wall consisting of small panels without HE connection will have lower shear capacity than the wall made of a single panel. As this example shows, the shear capacity of the wall would be governed by the strength of HE and VE connections. To design a small CLT panel shear wall having similar shear capacity to a single panel wall, The VE or HE connection needs to be strong for the wall not to fail mode B and C; hence, the global peak loads of the failure mode B and C should be higher than the global peak load of the failure mode A.

Even though the global peak load is governed by a bracket uplift failure (mode A), the global displacement would be affected by the all-failure mode. Therefore, the global displacement was assumed to be the sum of global displacements by all the failure modes (Eq. 10),

$$D = \sum (D_{\mathrm{uplift},b}, D_{\mathrm{uplift},v}, D_{\mathrm{shear},h}, D_{\mathrm{shear},v}). \qquad (10)$$

Materials and methods

Materials

Cross-laminated timber panels

CLT panels were manufactured with 3 layers. The outer layer was assembled in the same direction and the mid-layer was crossly oriented. As the outer layer, E11 or

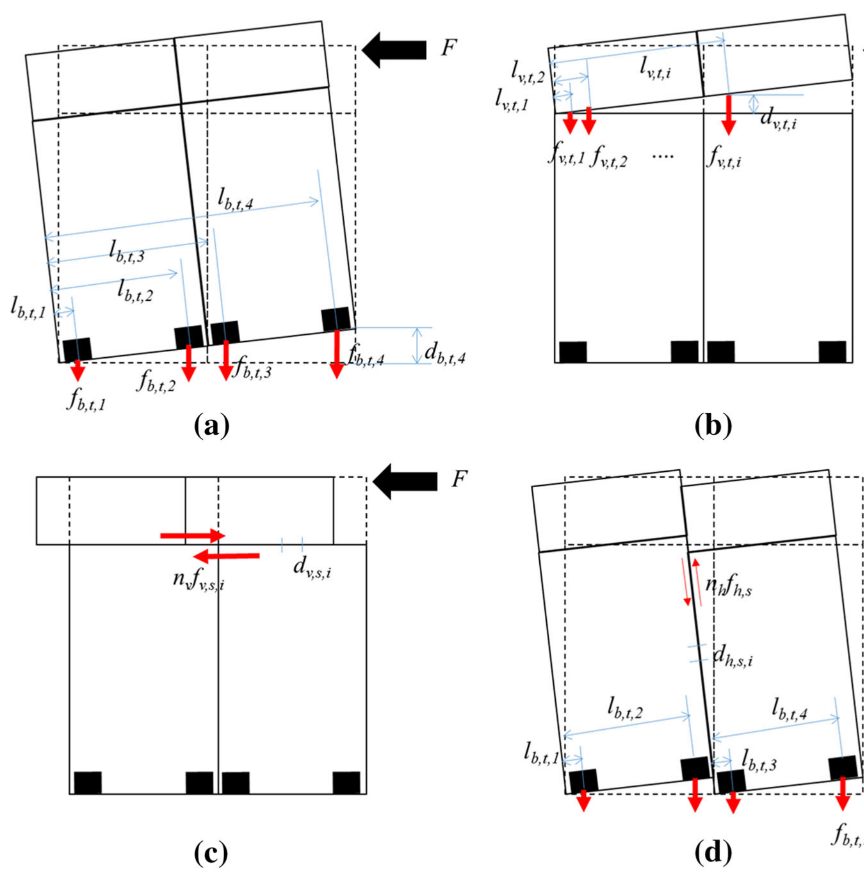


Fig. 2 Behavior of multiple-panel wall according to mode by the kinematic model. **a** Mode A. **b** Mode B-1. **c** Mode B-2. **d** Mode C

higher E-rated laminae were used, and E8 or higher E-rated laminae were used for the mid-layer. The grading was performed by Korea Forest Research Institute notification 2009-1 [10]. E11 means that its modulus of elasticity (MOE) is not lower than 11GPa. The lamina species was Japanese larch (*Larix kaempferi*). The average moisture content was 11.5 %. The thickness of the CLT panel was 90 mm, in which the thickness of all laminae was 30 mm.

Connectors

If the height of the panel is shorter than the height of the story, panel-to-panel connection is required to extend the panel up to the height of the story. Also, when the wall is wider than a panel, the panels need to be connected by the HE panel-to-panel connection.

In this study, single-spline connection and double-spline connection were used. As a spline, 18 mm thick OSB (Floor 23/32″ Stud-I-Floor grade) was used. In case of the single spline, the groove was made at the center of the thickness of the CLT panel and the two grooves of the double spline were made at the center with 18 mm spacing between the close edges. The depth of the groove was 60 mm. Screws of 5.4 mm diameter and 89 mm long (T12350DBB, Simpson strong tie) were used in the panel-to-panel connections.

For connecting the walls on the foundation, AE116 brackets (Simpson strong tie, Fig. 3) were used. Three half-inch bolts fixed the bracket on the foundation. The bracket was fixed on CLT by SD10212 (Simpson strong tie, USA) screws.

Experimental procedures

Test of unit connection

Basically, the fiber of the 2 outer layers in the 3 layer CLT must be oriented in vertical direction, because the wall should resist against vertical load. The inner layer would not play an important role of a load-resisting element against vertical load (Oh et al. [5]). Therefore, the single-spline connection was processed for the VE connection, in which a groove for connection was made in the inner layer only. In case of the HE connection, the inner layer should remain after the connection process. If there is no inner layer in the HE connection, the edge of the panel can be easily broken because the laminae in the CLT panel are glued on the wide face only. The cutoff of the inner layer for single-spline processing was not appropriate in the HE connection. Therefore, double-spline connection was used in the HE connection.

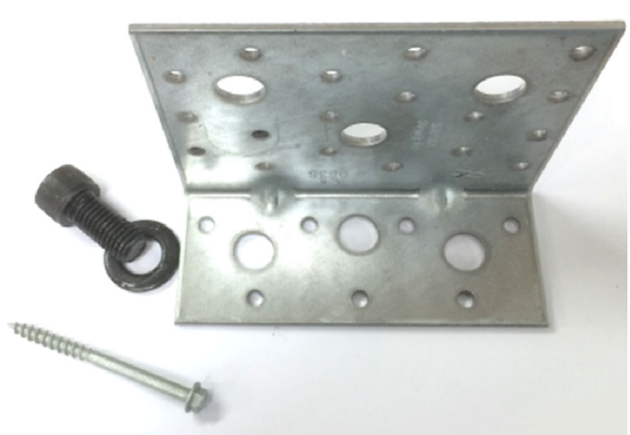


Fig. 3 Bracket (AE116, SD10212, 1/2″ Bolt)

By considering the stress type acting on the connections, the 4 test setups were prepared: the uplift of the VE and bracket and shear of the VE and HE connections. Two specimens were prepared for each test set. On the first specimen, a monotonic test was carried out. Based on the monotonic test result, the CUREE protocol for the next cyclic test was determined (ASTM E2126 [11]). On the second specimen, a cyclic test was performed by the determined protocol.

To measure the shear behavior of panel-to-panel connection against shear force, the specimen of unit connection was made as in Fig. 4. From the observed hysteresis curve, an envelope curve was obtained from the data of the first cycle direction (tension direction). Because two connections (4 screws) were used in the experiment, the envelope curve of the unit connection for shear was obtained by dividing the as-measured load by 2.

The VE connection needs to resist the uplift force as well as shear force. Therefore, the uplift test for the VE connection was carried out. Also, the uplift test for the bracket was performed in the same manner (Fig. 5). At the uplift test, half the CUREE protocol was applied, where only the tension direction protocol was used. An envelope curve of the unit connection was also obtained from the hysteresis curve.

CLT shear wall test

An objective in this study was to investigate whether the CLT shear wall made of small panels can be designed to have equivalent shear resistance as the CLT shear wall made of a single large panel. Based on the unit connection test result, the global force for each failure mode was calculated by equations formulated in the previous clause. By analysis using the result of the unit connection test and Eqs. 2, 4, 6 and 8, the number of screw required so as not to fail in panel-to-panel connection was decided.

Three types of CLT walls were prepared as in Fig. 6. Specimen S was made up of a single CLT panel and there

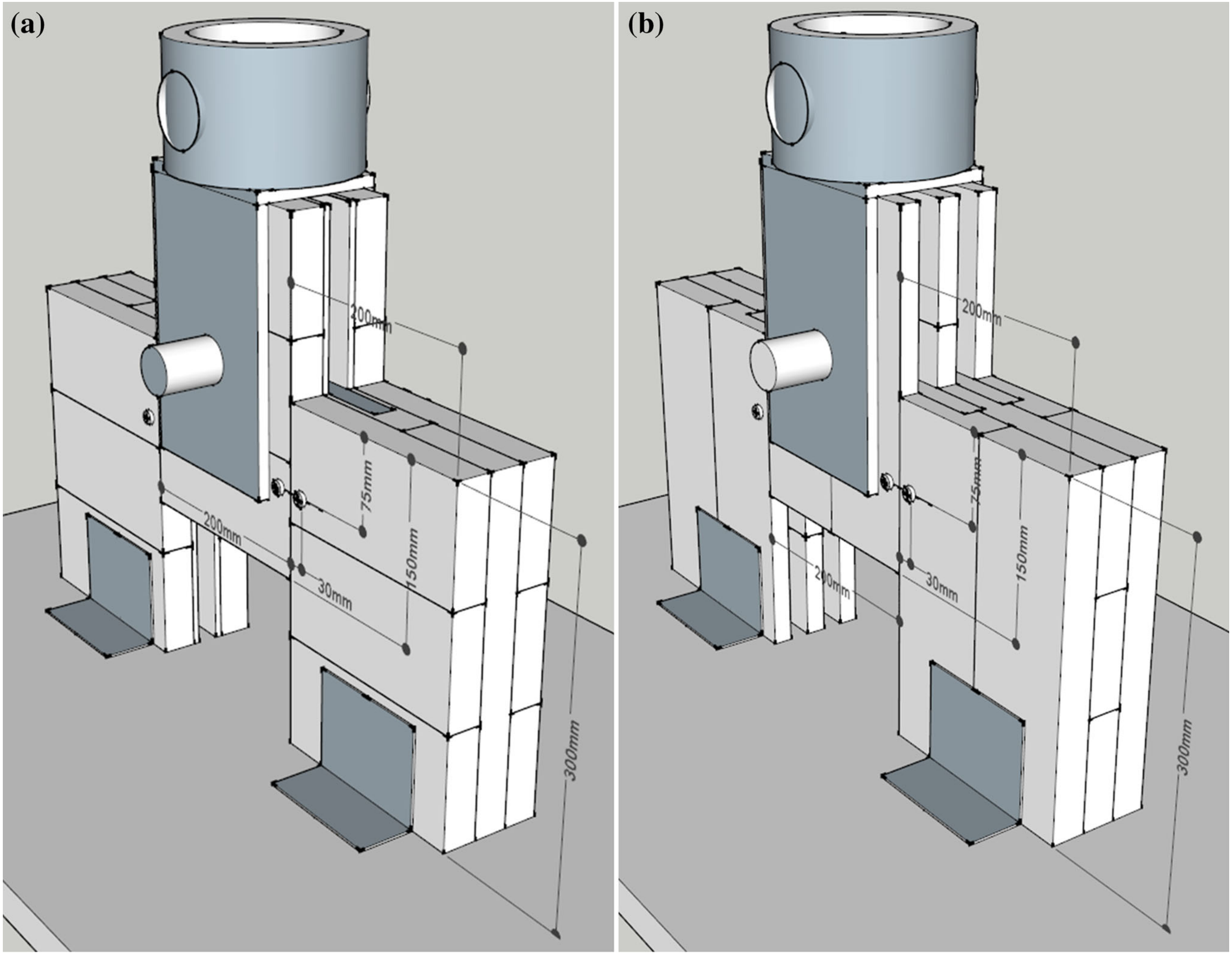


Fig. 4 Test setup for shear performance measurement of panel-to-panel connection. **a** Vertically extending connection. **b** Horizontally extending connection

was no panel-to-panel connection. It had only brackets at the bottom and the brackets were installed at the corner of the CLT panel 117.5 mm away from the edge of the panel.

Specimen D consisted of two CLT panels (1200 mm by 2400 mm, 90 mm thickness). The two panels were connected by 20 double-spline connections (40 screws) with 114 mm spacing at the center for the HE connection. The two brackets were installed at each panel at the same location as the Specimen S. Four brackets were installed in Specimen D in total as in Fig. 6.

Specimen B was the wall extended by connections in the vertical and horizontal directions. Two different connections were used: the HE connection and the VE connection. The VE connection was made up of 18 single-spline connections (36 screws, 120 mm spacing on center). The HE connection consists of 20 double-spline connections (40 screws, 110 mm spacing on center). There was no connection at the crossing point of the VE and HE connection line. The two brackets were installed per panel at the same location as Specimens S as shown in Fig. 6.

For each type of CLT wall, two pieces of specimens were prepared for monotonic test and cyclic test. The first specimen for each wall type was tested by a monotonic loading. Based on the result of the monotonic loading test, a protocol was defined by ASTM E2126 [11]. The second wall specimen was tested by the CUREE protocol defined by the monotonic test result.

The loading beam was placed on the top of the test wall as in Fig. 7a. The beam held both ends length-wise to transfer the cyclic load in both directions. Because there might have been some tolerance between the shoe of the loading beam and the test wall, a bolt clamping unit was made at the end of the loading beam (Fig. 7b). By adjusting the bolt, the test wall was tightly held in the shoe of the loading beam. For measuring global displacement, a laser displacement sensor was used as in Fig. 6.

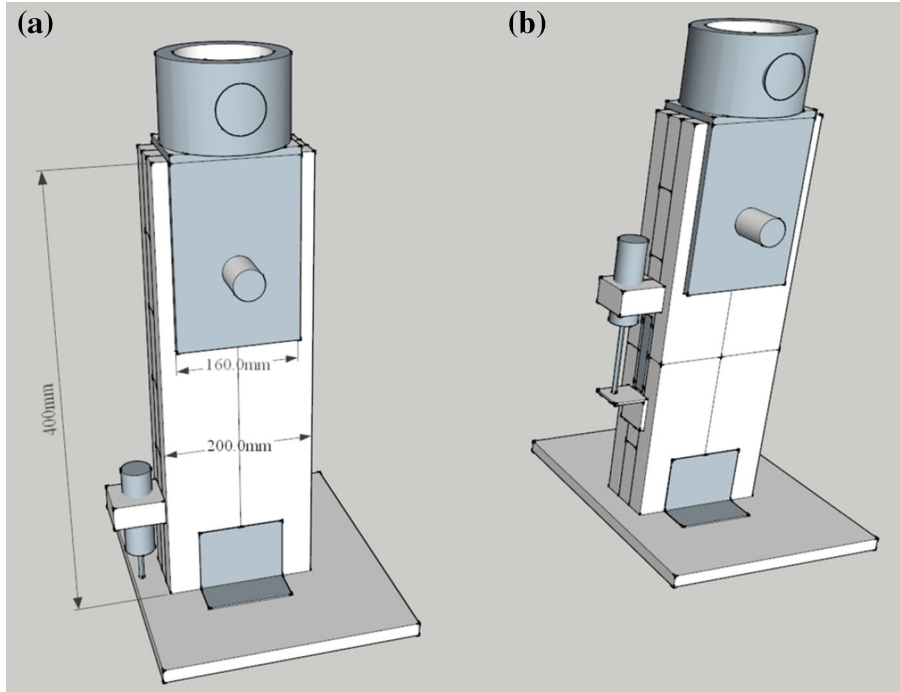


Fig. 5 Test setup for measurement for uplift resistance of bracket connection and vertically extending connection. **a** Bracket, **b** vertically extending connection

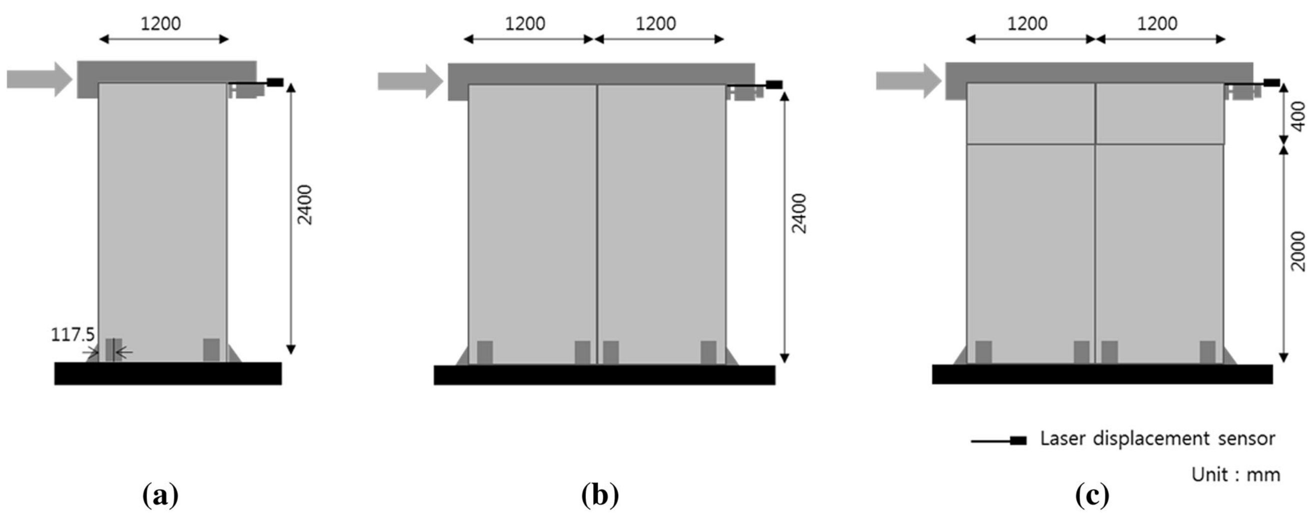


Fig. 6 Test wall for in-plane shear test. **a** Single wall without panel-to-panel connection (wall S). **b** Wall containing horizontally extending panel-to-panel connection (wall D). (The panel-to-panel connection was made by double-spline connection). **c** Wall containing both vertically and horizontally extending panel-to-panel connection (wall B) [horizontally extending connection was made by 20 sets of double-spline connection (110 mm spacing); vertically extending connection was made by 18 sets of single-spline connection (120 mm spacing)]

Prediction of the envelope curve from unit connection behavior

For each CLT wall, the peak load for each mode was calculated by the formula with the peak load of the unit connection test (Eqs. 2, 4, 6, 8). Figure 2 shows an example of wall B showing deformation for each mode of the kinematic model. In case of wall D, there was no mode B-1 and B-2, because it did not have VE connection. Also, wall S did not have mode B-1, B-2 or C; hence, wall S has mode A only which is the same as in Fig. 1a. Out of peak loads, mode A showed the minimum in the four peak loads and the failure mode of the CLT walls was expected to be mode A.

The maximum global displacements for the failure mode A were calculated by the corresponding displacement formula (Eqs. 1, 3, 5 and 7). To predict the envelope curve of the CLT wall, 10 displacement steps were defined based on the maximum global displacement of the failure mode A.

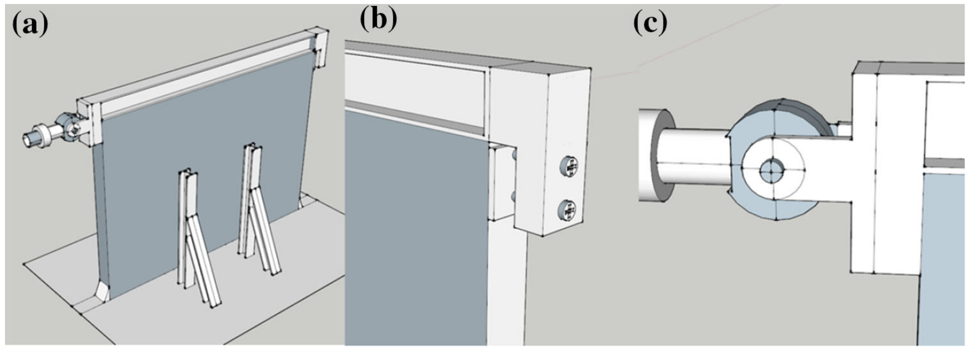


Fig. 7 Schematic diagram for loading apparatus for shear wall test. **a** Two lateral supports at each face (4 in total). **b** Loading beam on top of the test wall for reverse loading. **c** Loading beam on top of the test wall at the actuator side

The global shear wall resistance would be governed by the failure mode A, but the global displacement of CLT wall is not caused by a failure mode only. The other mode would also affect the total global displacement. Therefore, global displacements for the other mode have to be calculated and added to the global displacement of the failure mode A (Eq. 10). At each displacement step, the global displacements of the other mode under the global force of each displacement steps were calculated.

For mode B-2, the local force at a connection under a global force was calculated by inverse function of the formula (Eq. 6). Under the local force at the connection, the local displacement of the connection was calculated by linear interpolation of the envelope curve for unit connection. The global displacement was calculated by geometry and local displacement for the connection (Eq. 5). By this procedure, the global displacement for mode B-2 was calculated for each step.

In case of mode B-1 and C, the close form for inverse function of Eqs. 4 and 8 cannot be obtained. Therefore, the global displacement under a certain global force was calculated by the solver (Microsoft Excel 2013). For each step, this calculation was repeated and global displacements by mode B-1 and C for each step were calculated by the solver and interpolation of the envelope curve for the corresponding connection.

The total global displacement of the tested CLT wall for each displacement step was predicted by Eq. 10.

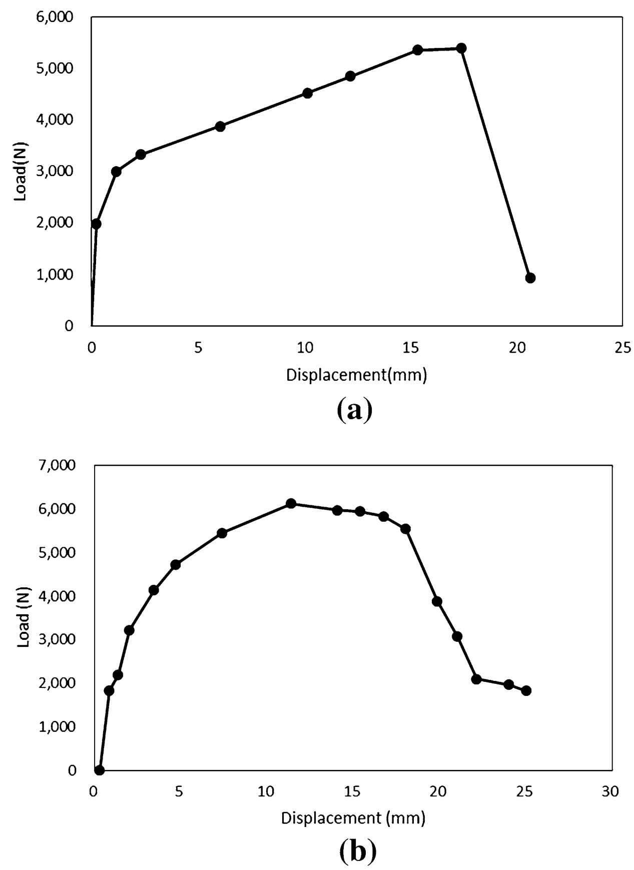


Fig. 8 Envelope curve of shear test for panel-to-panel unit connection. **a** Vertical-extending connection (single spline), **b** horizontal-extending connection (double spline)

Results and discussion

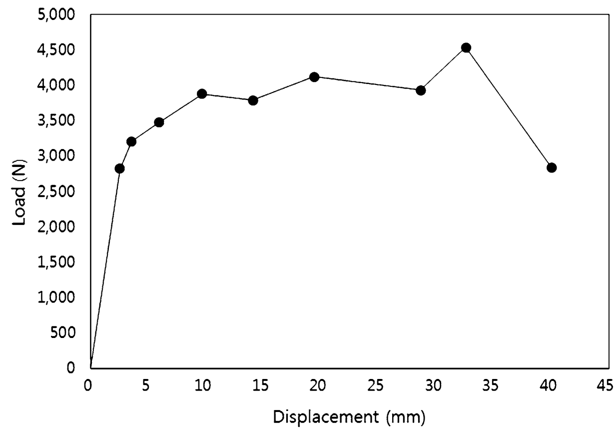
The experimental results of CLT shear wall and unit connection test

Four types of unit connection tests were carried out. Figures 8, 9 and Table 1 show the result summary and envelope curve for each unit connection test.

Three different types of CLT shear wall were tested by cyclic load. All CLT walls failed by uplift force at the bracket. In case of wall B, a small displacement at the VE and HE connections was found, but the VE and HE connections did not fail until the bracket failed. In case of wall D, the displacement was also found at the HE connection as well. But until the bracket failed, the HE connection did not fail.

Validation of the kinematic model for CLT shear wall containing panel-to-panel connection

The proposed kinematic model was expected to be able to simulate the envelope curves of the CLT shear wall



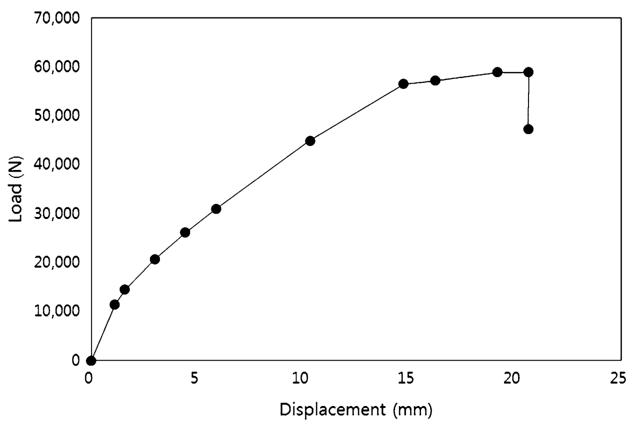


Fig. 9 Envelope curve of the uplift test (Half CUREE protocol). **a** Vertical-extending connection (single spline). **b** Bracket

containing panel-to-panel connection. Firstly, based on the envelope curves of unit connections, global peak loads for the four different modes were calculated. Originally, the wall and connections were designed for the wall to fail by failure mode A (uplift at bracket). As expected, the actual failure mode was the failure mode A.

The global displacement was also predicted by Eq. 10. For the prediction of global behavior of the CLT shear wall; the global displacement at the top corner of the wall specimen was compared with the prediction by the kinematic model. Figure 10 shows the as-measured envelope curve and the simulated envelope curve for walls S, D and B. The kinematic model was very similar to the measured envelope curve. From this result, it was concluded that the proposed kinematic model can predict the shear behavior of a CLT wall containing panel-to-panel connections.

Table 2 shows the comparison between the predicted and measured peak load of the CLT walls S, D and B. The peak load of wall S was identical to the prediction. walls D and B showed a slightly lower peak load than the prediction (Less than 10 %). Nevertheless, the model seems to predict the peak load with reasonable accuracy.

Influence of panel-to-panel connection on the performance of the CLT shear wall

The wall B not only has HE connection, but also VE connection. The presence of VE connection in wall B was the only difference from wall D. In this case, the peak load of wall B was higher than that of wall D (Table 2), though wall B had VE connections additionally. This indicates that the VE connection did not make a significant effect on the peak load.

Also, the peak load of wall B showed only 3.1 % disagreement with the prediction by the kinematic model (Table 2). The peak load was predicted by Mode A only. The formula of this mode is exactly the same as that of the CLT wall which is made of a single CLT panel. The formula for Mode A has already been validated by FPInnovations and Binational Softwood Lumber Council [7] and also in this study re-validated by the comparison between experiment and prediction of of wall S. The small difference of 3.1 % for wall B indicated that wall B is only 3.1 % weaker than the same size CLT wall made of a single CLT panel. In other words, the HE connection of wall B also did not make a significant effect on the load resistance.

Originally, the VE connection and HE connection were designed not to fail in these connections. This means that the CLT shear wall could be designed without large loss in

Table 1 Results of the unit connection test

Type of stress	Type of connection	Related mode[a]	Peak load (N)	Displacement at the peak load (mm)
Shear	VE connection	Mode B-2	5382	17.4
	HE connection	Mode C	6121	11.4
Uplift	VE connection	Mode B-1	4539	32.6
	Bracket	Mode A	58883	19.2

VE vertically extending, *HE* horizontally extending

[a] This was defined in this paper (Eqs. 1–9; Fig. 1)

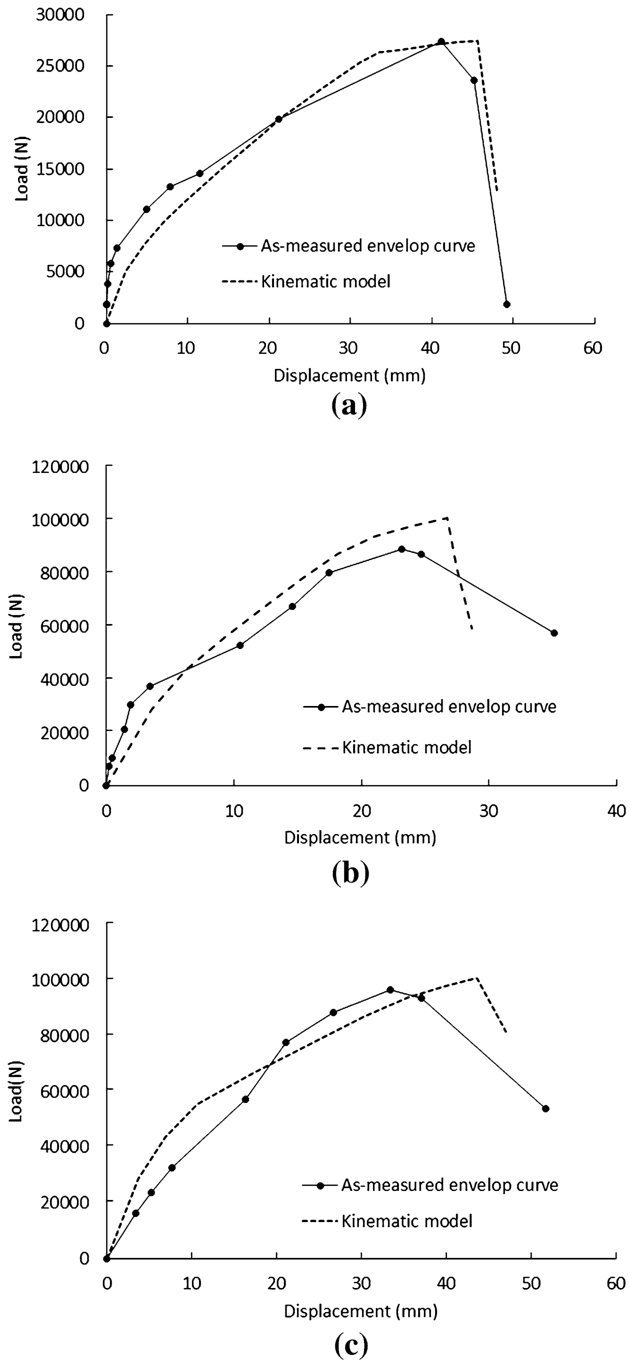


Fig. 10 Prediction of envelope curve by the proposed kinematic model. **a** Specimen S, **b** Specimen D, **c** Specimen B

Table 2 Comparison of peak load between measurement and prediction

Wall	Peak load (kN)		
	Measurement	Prediction	Difference (%)
S	27.3	27.3	0 (0.0)
D	89.9	99.6	−9.7 (−9.7)
B	96.5	99.6	−3.1 (−3.1)

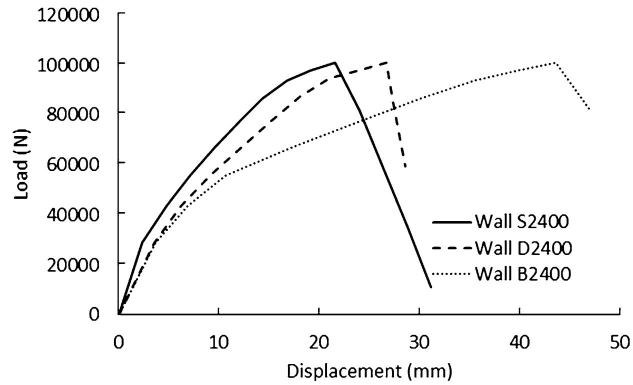


Fig. 11 Global displacement according to the presence of panel-to-panel connection (kinematic model calculation). *All test walls have the same dimension (2400 mm in length and 2400 mm in height). All test walls have the same boundary condition in the bracket. Wall S2400 does not have any panel-to-panel connection. Wall D2400 has HE connections in the middle. Wall B2400 has VE and HE connections at 2000 mm height

peak load, even though small CLT panels were used to make a CLT shear wall.

Figure 11 shows the kinematic model analysis on the influence of panel-to-panel connection on global displacement. The three walls of S2400, D2400 and B2400 have the same dimension and the same boundary condition in bracket (same as wall D and B). But the S2400 was made of a single large size CLT panel without panel-to-panel connection. The D2400 had HE connection in the middle and was made of small-size CLT panels. The B2400 has both HE and VE connections at 2000 mm height. For the three CLT walls, the kinematic model provided the same peak load because the failure mode would be the same, Mode A: uplift of the bracket. However, the global displacement significantly increased as panel-to-panel connections were added, as shown in Fig. 11. This means that the CLT shear wall made of small CLT panels can deform much more than the CLT wall made of a single large panel. This increase of deformation indicates that small panels can be used to make a large CLT shear wall without significant strength loss, but the structural designer and code developer should consider the deformation of the wall with meticulous care.

Conclusion

The use of small CLT panels for making a large shear wall requires many panel-to-panel connections. When designing a large CLT wall with small panels, the designer must ensure that the wall does not fail by the HE and VE connections and by the uplift at the bracket like a single panel wall. In this study, additional kinematic formulae for panel-to-panel failure were made. Using the formulae, the two

CLT shear walls containing panel-to-panel connection were designed to fail at the bracket by the uplift force and were experimentally investigated. Also, using the kinematic formulae the envelope curves were predicted.

In all tested walls, failure occurred at the bracket by the uplift force as designed by the kinematic formulae and the predicted envelope curves showed good agreement with the experimental results. It was investigated whether the shear wall made of small CLT panels would have equivalent resistance to the CLT shear wall made of a single large CLT panel, by experimental and kinematic model analysis. The VE and HE connections did not show a significant strength loss, but the global displacement increased as connections were added. This analysis indicates that small panels can be used to make a large CLT shear wall without significant strength loss, but deformation is much larger than in the wall made of a single panel. Therefore, careful consideration on deformation is required.

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