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Influence of openings on the shear strength and stiffness of cross-laminated timber panels

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Abstract— **The influence of openings in CLT walls is an important aspect, and it is presently poorly understood. Concerning this aspect, the code regulations in Japan are relatively strict. The aim of this study is to evaluate the reduction of strength and stiffness in CLT panels due to openings. In this study, seven 5-layer CLT panels containing different openings were tested using a diagonal compression test. The effect of openings on the reduction of stiffness was found to be greater than the effect on strength reduction.**

I. INTRODUCTION

In the last decade, cross-laminated timber (CLT) has been receiving increasing attention as a promising construction material. Compared to other mass timber materials, CLT is a homogeneous material. This makes it a good candidate for use in shear walls in mid-rise buildings. However, openings are often necessary in CLT panels either in form of windows, doors or installation of building services. The effect of these openings on shear strength and stiffness of CLT shear walls are still not well understood. The limitations of opening size in CLT panels are described in the Japanese CLT Manual[1]. However, those regulations are relatively strict, such that if openings exceeded certain prescribed limits, the entire CLT panel is considered as a non-structural element.

II. BACKGROUND

Dujic et al.[2] proposed two equations to calculate reduction in strength and stiffness. In addition, Shahnewaz et al.[3] proposed an equation to calculate stiffness of CLT shear walls with openings based on a finite element parametric study. In all these tests, CLT walls had wall-to-floor connections, and hence this affected the global strength and stiffness characteristics of the tested shear wall. Thus the effect of openings on strength and stiffness characteristics of only the CLT panels cannot be obtained from these tests.

Okabe et al.[4] and Araki et al.[5] tested various CLT panels with multiple sizes of openings. The foundation-to-wall connections used in these tests was strong enough to ensure the failure in the CLT panels. However, in both of these studies the reference CLT wall without opening did not fail due to insufficient loading jack capacity. In addition, the connections in these studies deforms and affect the measured CLT panel stiffness. Therefore, the results from these studies also do not represent the behaviour of only the CLT panel.

Based on the previously mentioned tests, a study to evaluate the strength and stiffness of only CLT shear walls is needed. Thus, the objective of this study is to evaluate the shear strength and stiffness of CLT panel with openings without the influence of foundation-to-wall connections.

III. EXPERIMENTAL PROGRAM

In this experimental program eight 1200mm by 1200mm CLT panels were tested using a diagonal compression test as shown in Fig.1. One panel was a solid panel without opening while the rest of the panels had openings with different sizes and layouts. Only one of these configurations (A1-1) is considered a structural element according the Japanese CLT Manual[1] regulations. Table 1 gives an overview of the tested walls where H, L, h_o, l_o are the height and length of the wall and height and length of the opening, respectively. It was assumed that panel 'strong' shear strength direction is the direction in which three of the wood layers are perpendicularly oriented, and the 'weak' shear strength direction is the opposite direction where only two wood layers are perpendicularly oriented.

TABLE I
TEST MATRIX OF CLT PANELS

Name	L (mm)	H (mm)	l_o (mm)	h_o (mm)
A0-0	1200	1200	-	-
A2-2	1200	1200	200	200
A4-1	1200	1200	100	400
A1-4	1200	1200	400	100
A4-4	1200	1200	400	400
A8-2	1200	1200	200	800
A2-8	1200	1200	800	200
A6-6	1200	1200	600	600

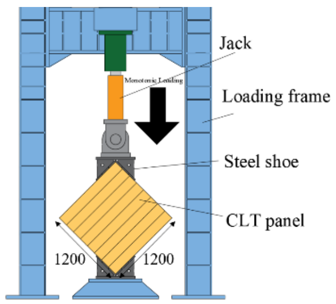

Fig. 1 – Loading set up details

IV. RESULTS

A. Damage and failure characteristics

Fig. 2 illustrate the crack patterns observed on the surface layers of the CLT panels after failure. The failure plane of all the specimens was parallel to the weak direction (i.e., parallel to grain for three wood layers and perpendicular to grain for two wood layers) except for specimen A1-4 and A2-8 that failed in the strong direction. The red and green lines in Fig. 2 indicates the failure direction in the weak and strong directions, respectively. All the specimens failed from corner to corner of the opening.

B. Force deformation response

Fig. 3 indicates shear force-shear deformation curves for all the tested CLT panels. It can be observed that except panel A6-6, all the panels experienced sudden loss of load carrying capacity after the maximum load was reached. Specimen A6-6 experienced considerably higher flexural deformations which resulted in a more ductile failure mode The stiffness was calculated in the linear part of shear-deformation curve between the values that are corresponding to 0.1 and $0.4F_{max}$.

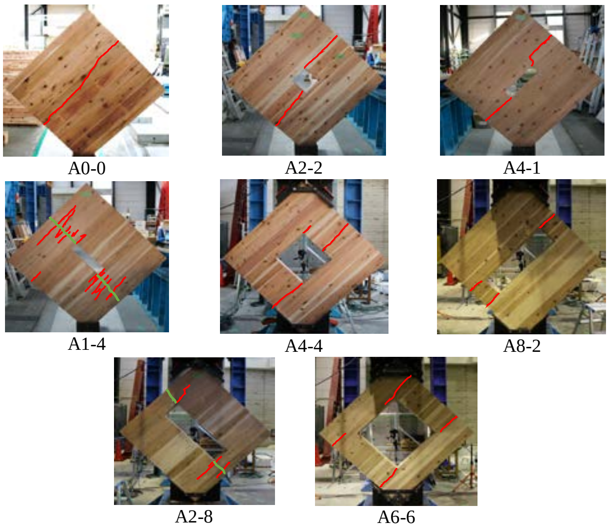

Fig. 2 – Cracks observed on the surface layer of CLT panels after failure

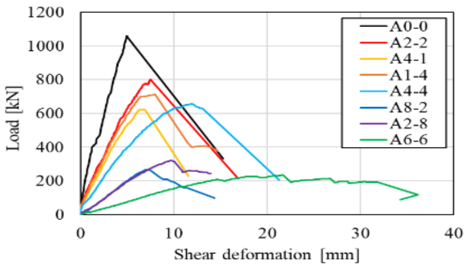

Fig. 3 – Load-deformation curves for all the specimens

C. *Shear strength and stiffness reduction due to opening*

Fig. 4 illustrates the effect of area of opening on the reduction in strength and stiffness for CLT walls with openings with the same aspect ratio. It can be observed that reduction in stiffness is larger than reduction in strength. Also, the bigger opening has greater effect on strength and stiffness reduction than small openings. On the other hand, the effect of aspect ratio of the opening on reduction in strength and stiffness for CLT walls with openings with the same area is shown in Fig.5. It can be concluded that the longest direction of opening has more influence than area of opening. Direction of opening has an effect on the reduction of strength and stiffness (in weak or strong direction).

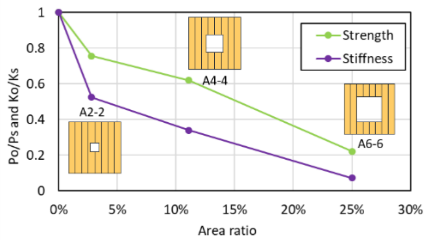

Fig. 4 – Reduction for walls with 1:1 aspect ratio

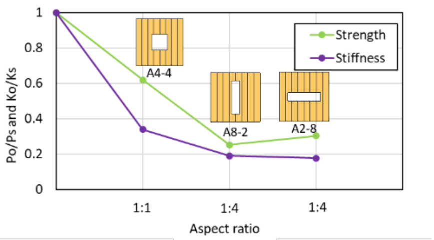

Fig. 5 – Reduction for walls with 1:1 aspect ratio

LVDTs were attached throughout the specimens, which are then used to calculate shear and flexural deformation through different sections of the panels. Fig. 6 indicates the relation between the area of the opening and the internal shear and flexural deformation for CLT panels with 1:1 aspect ratio. It can be seen that for walls with small area openings the shear deformation is dominant. Flexural deformation is dominant in specimen A6-6.

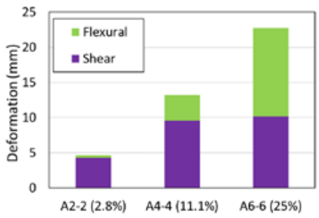

Fig. 6 – Internal deformation vs. opening area

Finally, a comparison between the reduction factor calculated using the Japanese CLT Manual[1] and the experimental reduction factor for strength and stiffness for all the specimens is shown in Fig. 7. It can be seen that the manual equation underpredicts the reduction in stiffness. Also, regarding strength reduction, A4-1 and A8-2 specimens do not match the experimental values, and that is because the manual equation does not take the effect of weak and strong direction into account.

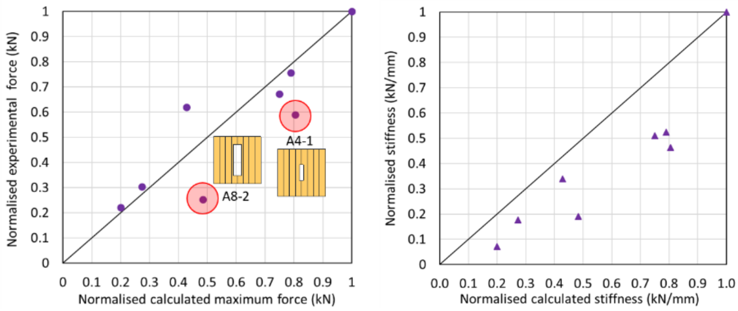

Fig. 7 – calculated vs. experimental reduction: strength (left), stiffness (right)

V. Conclusion

Diagonal compression tests on seven CLT panels with variables opening sizes were conducted to evaluate shear strength and stiffness reduction due to these openings. The main findings of this experimental study are as follow:

- The probable failure direction is the direction of the longest dimension of opening
- Flexural deformation increases as the opening size increases.
- The reduction in stiffness for CLT walls with openings was more than that in strength.
- CLT manual equation underpredicts stiffness, and has discrepancies with regard to strength as the difference of panel strengths in weak/strong directions are not considered.

Acknowledgment

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