Study on the influence of openings on the strength and stiffness of CLT wall panels
Part 3: Comparison of the experimental results with FEM analysis

Keyword:
CLT　　Walls with openings
FEM　　In-plane shear stiffness

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1. Introduction

In part 1 and part 2 of this study the experimental program and results of diagonal compression tests of CLT panels with openings were reported. In order to investigate the effect of opening parameters beyond those in the experimental program, a finite element model (FEM) model can be utilized. In this part (part 3) an FEM modelling approach is presented and the model results are then compared to the experimental results with regard to the changes in initial stiffness and maximum strength of the panels as larger openings are introduced. A comparison is also made between the ratio of shear to flexural deformation as observed in tests results; as determined using a simplified calculation method (previously described in part 1 and part 2) and the proposed FEM model.

2. FEM model description

2.1 Model assumptions

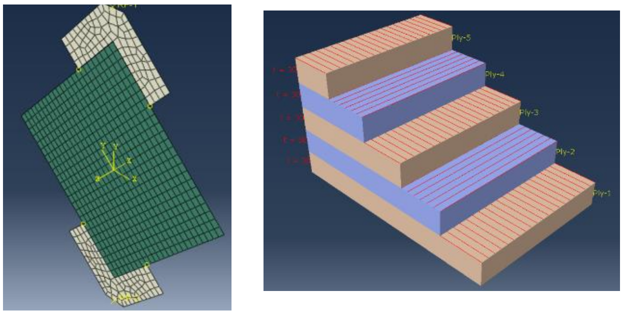
A numerical model was created using the finite element analysis software Abaqus [1]. The CLT panel was modelled using 'conventional' shell elements (i.e., thin shell element assumption) as shown in Figure 1.a. The CLT section is defined as a shell composite section with 5 layers, each layer with axis orientation perpendicular to the adjacent layer as seen in Figure 1.b. The CLT panels was meshed using uniform seeds with a seed size of (50 mm). The S4R element type was used in meshing, which is a 4-node shell element with reduced integration. The steel shoes that were used to apply load in the experiment were modelled as elastic shell element as well. The mechanical properties of this steel shoe was the same as elastic material properties for typical steel material. The contact between the steel shoes and the CLT panel shell elements was modelled as a tie connection with no relative movement between the nodes (i.e., no slip assumption). The FEM analysis was carried out assuming elastic conditions. The bottom steel shoe was fixed in all directions while a constant axial load is applied to the top shoe, that was fixed in all directions except vertical direction, in the vertical direction as static monotonic loading.

2.2 Material properties

The CLT panel used in this study consisted of five layers. Each layer was modelled as an elastic orthotropic material with three directions: longitudinal (in the direction of the grain), radial and tangential. The mechanical properties of each wood layer in each one of the orthotropic directions are shown in Table 1. The material properties of each layer in the CLT were determined using the characteristics of Japanese Cedar in Japanese Wood Industry Handbook [2].

Table 1: Japanese Cedar material properties.

Species	Young modulus (MPa)			Shear modulus (MPa)			Poisson ratio		
	E_L	E_R	E_T	G_{LT}	G_{LR}	G_{RT}	ν_{LT}	ν_{LR}	ν_{RT}
Japanese cedar	8700	620	260	460	650	15	0.58	0.405	0.901



(a)　(b)
Figure 1: Shell element model of CLT (a) overall model set up and mesh, (b) layered shell structure.

3. Experimental results

3.1 Shear stiffness

Figure 2 shows a comparison between experimental and analytical shear force-displacement curves. The analytical stiffness was slightly larger than that observed experimentally in all cases except A0-0. Overall, panels with small openings (A2-2, A4-1, A1-4 and A4-4) showed good agreement with the elastic portion of the experimental results. On the other hand, for panels with large openings (A8-2, A2-8 and A6-6) the experimental initial stiffness was lower than the initial stiffness in the FEM results by a ratio of around 1.5. This might be due to the start of the inelastic deformation in early stages of loading in these panels, whereas the FEM is only considering elastic analysis. A comparison between the experimental and numerical initial stiffness (i.e., stiffness calculated between 0.1 and 0.4P_{max}, where P_{max} is the maximum compression load achieved in the experiment) for all the panels is shown in Figure 3. Although the analytical stiffness is higher for all the panels with openings, except panels with large openings (A8-2, A2-8 and A6-6), a good tendency and fair estimations of the initial stiffness was found as shown in Figure 2. On average the initial stiffness determined from FEM was found to be 1.37times the experimental initial stiffness.

CLT パネルのせん断耐力・剛性に開口が及ぼす影響に関する研究
その３　FEM 解析による剛性および変形性能の評価

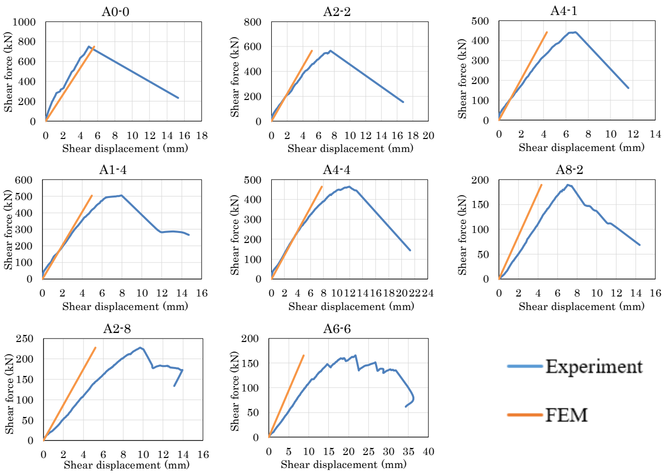


Figure 2: Comparison between experimental and analytical force-displacement curves.

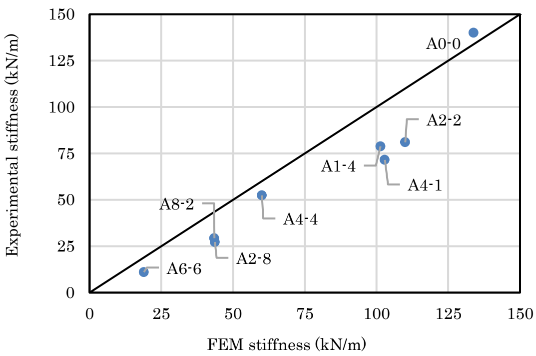


Figure 3: A comparison between experimental and analytical stiffness for all panels.

3.2 Internal shear and flexural deformation

A comparison between the experimental and analytical values of the overall deformation for all the panels at $0.4P_{max}$, is shown in Figure 4. $0.4P_{max}$ represents the end of the elastic deformation phase for the CLT panels. With the exception of panels with a large opening size (A8-2, A2-8 and A6-6) the analytical results of the deformation showed good agreement with the experimental values. These results are compatible with the analytical and experimental values for the initial stiffness of these panels. The analytical values were around 2 times larger in the case of A6-6 panel. One possible reason is the larger inelastic flexural deformation that A6-6 panel experienced at early stages of loading (demonstrated by parabolic backbone curve of load and drift shown in Figure 2) which is not considered in the FEM elastic models. Relative internal shear and flexural deformation taken at $0.4P_{max}$ as determined using the FEM model and a simplified calculation approach (described in part 1 and part 2) are compared to the experimentally determined values in Figure 5. The deformation components as determined using the FEM model reasonable agreement with the experimental results for all the panels, with the differences in the range of 10~20%. In experiment and FEM, internal shear deformation was more dominant in all panels at $0.4P_{max}$, even for panels with large openings (A8-2, A2-8 and A6-6).

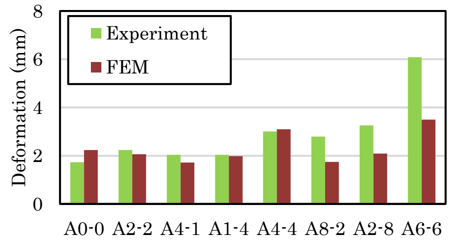


Figure 4: A comparison between experimental and FEM overall deformation for all specimens at $0.4P_{max}$.

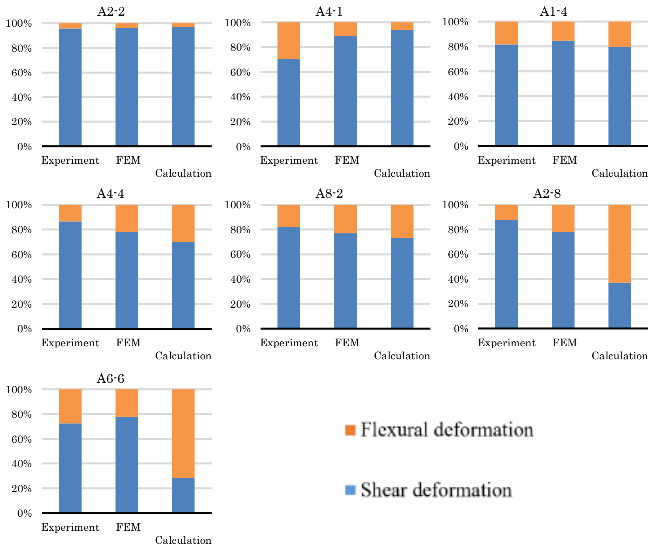


Figure 5: A comparison between experimental, FEM and calculation internal shear and flexural def. ratio at $0.4P_{max}$.

4. Conclusion

Diagonal compression test of CLT panels with openings were simulated FEM analysis and compared to the experimental results. The following are the main findings:

1- The proposed model showed fair estimation of initial stiffness for CLT panels with no openings or with small openings.

2- For panels with relatively large opening size, the FEM models overestimate the initial stiffness with ratio of around 1.5~2.

3- The ratio between the internal shear and flexural deformation was compared at $0.4P_{max}$. The flexural deformation of FEM models showed good agreement between experimental and FEM results with differences in the range of 10~20%.

4- The simplified calculation of deformation components at $0.4P_{max}$ also showed good agreement with experimental results for the ratio of shear and flexural deformation for all panels. Except for specimens A2-8 and A6-6 were the calculated flexural deformation was determined to be about two times larger than the observed results.

Further study is needed to improve the accuracy of FEM models especially for panels with very large openings.

References

[1] Dassault Systemes Simulia Corp., Abaqus software 2019 student edition.
[2] Basic theory of wood structure: Architectural Institute of Japan: Wood Industry Handbook (4th Edition).

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