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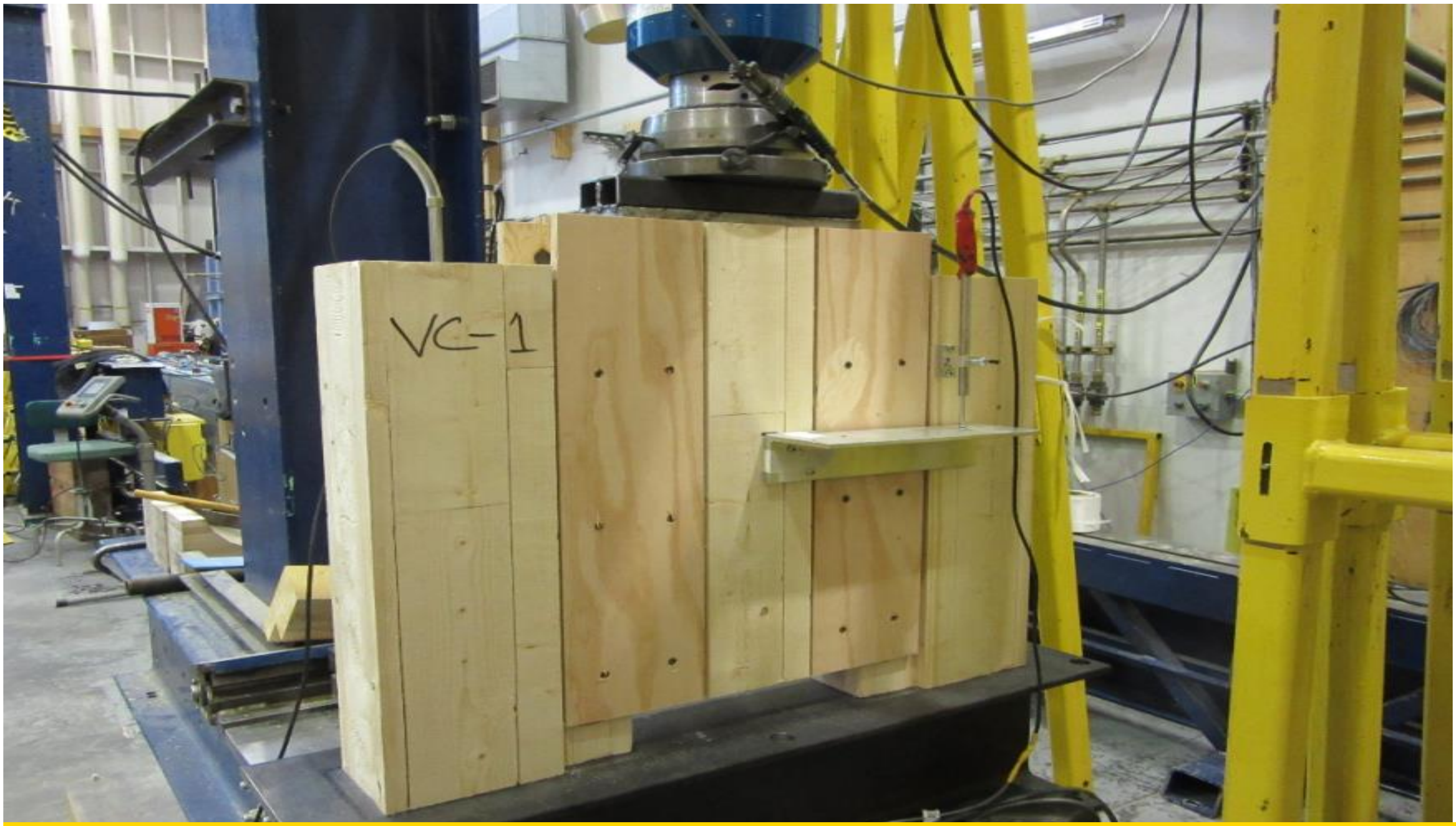

Monotonic Quasi-static Testing of CLT Connections (REVISED – Version 3)

Date: June 30, 2015

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1 INTRODUCTION

This testing program was carried out by the Advanced Building Systems (ABS) Department of FPInnovations in response to a request from Mrs. Julie Frappier from Nordic Engineered Wood for the evaluation of the mechanical properties of three (3) different assemblies for attaching Cross Laminated Timber (CLT) panels. Each of the assemblies consisted of six (6) specimens for a total of eighteen (18) tests. All specimens were manufactured by Nordic Engineered Wood and delivered to FPInnovations' laboratory in Québec City.

2 OBJECTIVE

The key objective was to evaluate the mechanical properties pertinent for the design of CLT panel connections exposed to in-plane loading such as diaphragms or shear walls. The evaluation of the ultimate loading capacity ($\mathbf{P_{ult}}$) and the stiffness (**K**) of the connections are thus the main focus of this study.

3 METHOD IDENTIFICATION

Testing procedures were performed in accordance with the principles of ASTM D 1761-12, Standard Test Methods for Mechanical Fasteners in Wood.

4 DESCRIPTION OF SAMPLES AND SAMPLING METHOD

The test matrix consisted of three (3) series or assemblies each consisting of a 3-PLY CLT panel (Nordic XLAM) with two additional CLT panels attached to each extremity as shown in Figure 1. Every connection consisted of plywood panels at both faces attached with mechanical fasteners and two of the assemblies combined the fasteners with adhesives. The dimensions of the CLT panels, plywood panels, and fastener location were identical for every assembly (see Figure 1). The detailed description of the mechanical fasteners and adhesives used in each of the three (3) assemblies are given in Table 1. In essence, Series C consists of nails only, Series VC consists of wood screws in combination with PL Premium adhesive, and Series VCPB consists of wood screws in combination with Purbond HB181 adhesive. Each series consisted of six (6) specimens for a total of eighteen (18) specimens tested.

A manufacturing defect was noticed for Specimens C1 and VCPB 6. Both specimens were found to be missing one of the mechanical fasteners out of the usual twenty-four.

Monotonic quasi-static tests were performed to determine the ultimate loading capacity ($\mathbf{P_{ult}}$,), and the slip modulus or stiffness (**K**) of the assembly provided (i.e., considering both shear planes). The total length of one shear plane is 18" (457mm) as shown in Figure 1 a.

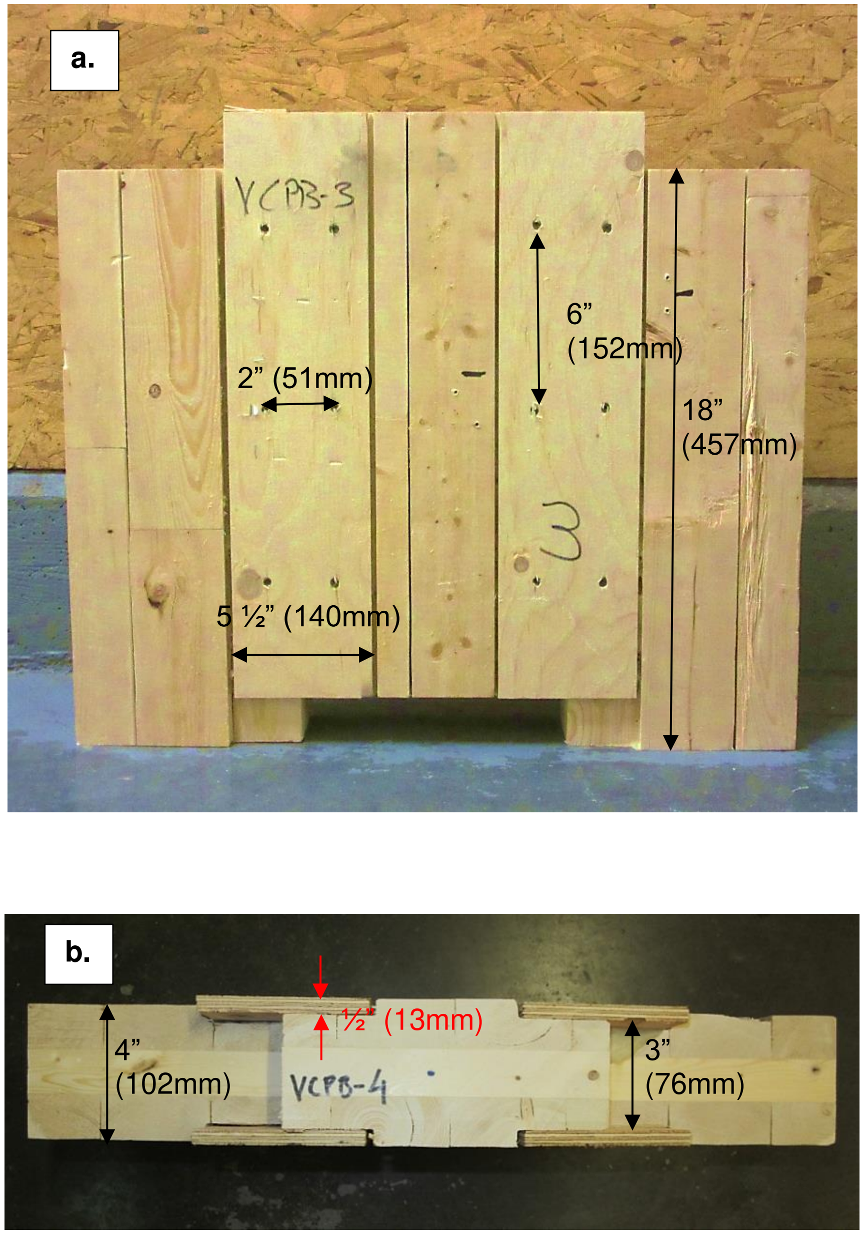

Figure 1. (a) Front view of a typical assembly (b) Top view of a typical assembly

Table 1 - Description of connection system for each assembly

Series Name	Mechanical Fastener			Adhesive
	Type	Diameter (mm)	Length (mm)	
C	Common nail	3	76.2	none
VC	Wood screw	3	57	PL Premium
VCPB	Wood screw	3	57	Purbond HB181

The loading apparatus used for Series C was a 100 kN capacity material testing system with a spherical bearing block used to exert the compressive loading. A material testing system with a capacity of 250 kN was used for Series VC and VCPB due to the higher anticipated strength of such systems. A custom load transfer block was manufactured in order to ensure that the surface of the spherical bearing block did not enter into contact with the plywood panels ensuring that the fastening system is not indirectly loaded. Two (2) linear variable differential transformers (LVDTs) were installed on the CLTs at the extremes (static) and at opposite faces in order to measure the displacement with respect to the central CLT (dynamic). Figure 2 shows a typical specimen ready for testing.

A loading rate of 2 mm/min was used for Series C and a loading rate of 0.5 mm/min was used for Series VC and VCPB to ensure that the ultimate load is always reached within the range of 5 to 20 min as per ASTM D 1761-12. This condition was successfully met for every specimen. A data acquisition rate of 5Hz was used for all tests.

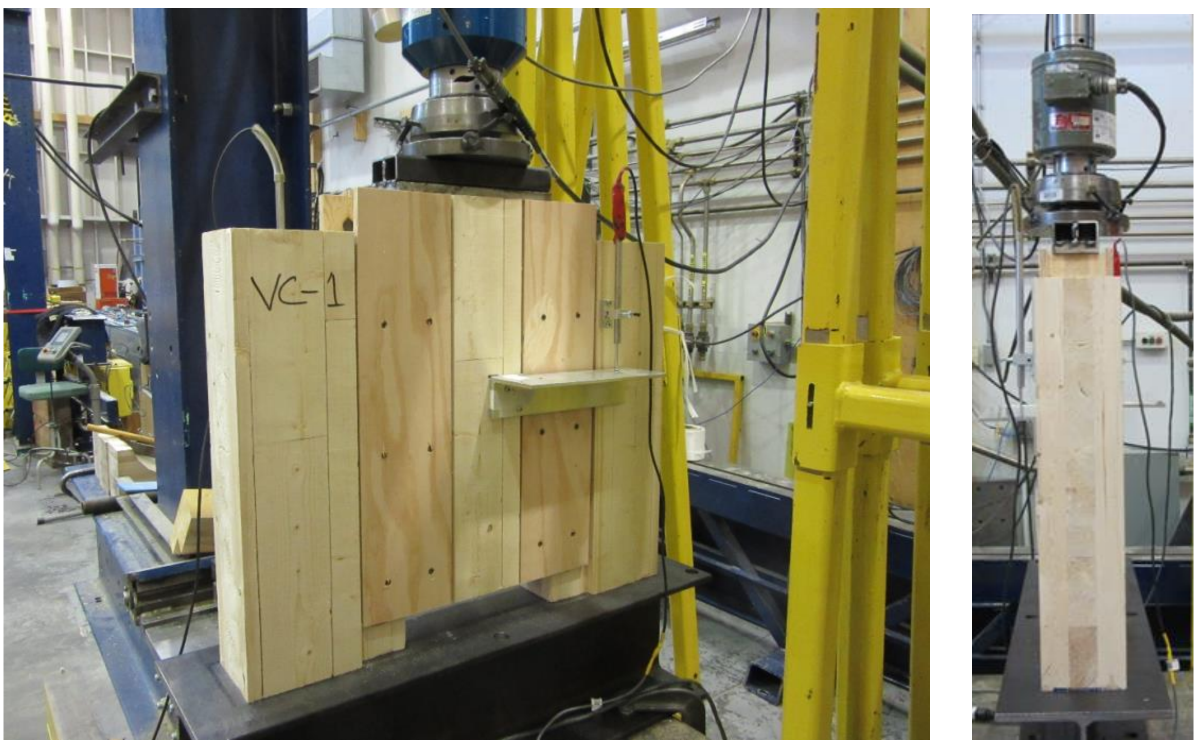

Figure 2. Specimen VC1 in place for testing

5 TECHNICAL TEAM

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Anes Omeranovic	Principal Technologist, Advanced Building Systems

6 DATES OF RECEPTION OF SAMPLES

The specimens were received on the second week of January 2015 at FPInnovations' laboratory in Québec City.

7 DATES OF TESTING

Tests commenced on January 26, 2015 and were completed on January 28, 2015.

8 RESULTS

8.1 Test Results

The results for ultimate loading capacity ($\mathbf{P_{ult}}$), displacement at ultimate load ($\Delta_{\mathbf{P_{ult}}}$), and slip modulus or stiffness (**K**), are presented in Tables 2, 3, and 4 for all specimens of Series C, VC, and VCPB respectively. Statistical data for each of the three (3) series are also provided. The slip modulus (**K**) was determined from the slope of the linear section of the load-slip curve between the points of 10% and 40% $\mathbf{P_{ult}}$. The deformation at the ultimate load ($\Delta\mathbf{P_{ult}}$) was also obtained from the load-slip curve for each specimen.

It is important to note that all of the data presented in this report refers exclusively to the eighteen (18) specimens included in this study. Furthermore, $\mathbf{P_{ult}}$ refers to the load applied to the whole assembly (i.e. total load from actuator).

The load-deformation graphs for each specimen are also presented in Figures 3, 4, and 5 for Series C, VC, and VCPB respectively.

Table 2 - Test results for Series C

SPECIMEN	P_{ult}, kN	Δ_{Pult}, mm	K, kN/mm
C1	16.99	6.83	26.58
C2	24.72	30.06	6.16
C3	19.88	25.50	4.14
***C4**	16.00	9.57	12.91
C5	22.64	32.85	6.33
C6	16.99	9.00	14.28

Min	**16.00**	**6.83**	**4.14**
Max	**24.72**	**32.85**	**26.58**
AVG	**19.54**	**18.97**	**11.73**
Std. dev.	**3.52**	**11.77**	**8.32**
CV%	**18.04**	**62.07**	**70.92**

*Manufacturing defect: one nail missing

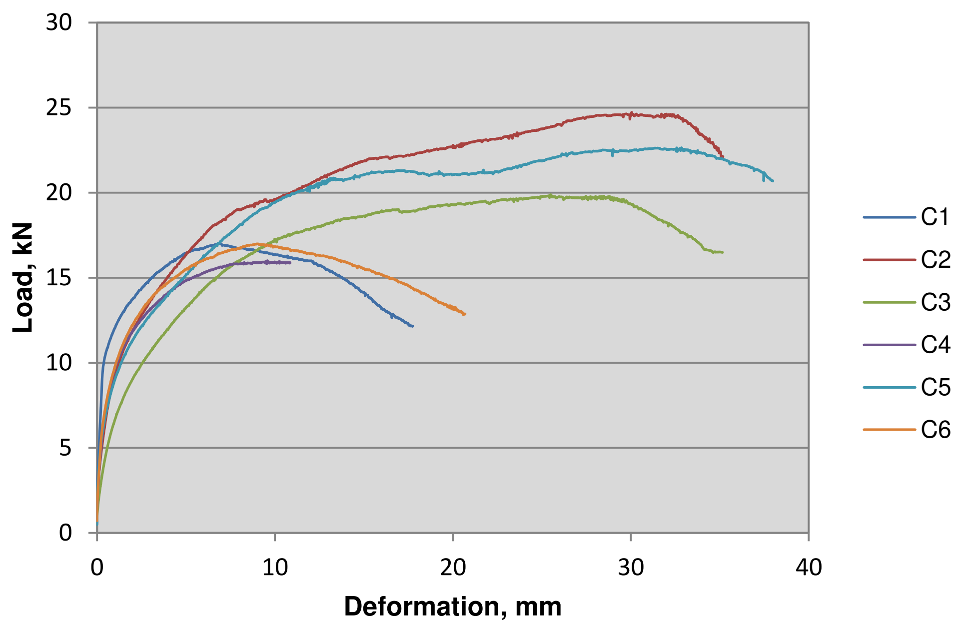


Figure 3. Load-deformation curves for all specimens of Series C

Table 3 - Test results for Series VC

SPECIMEN	P_{ult}, kN	Δ_{Pult}, mm	K, kN/mm
VC1	198.78	1.12	277.32
VC2	152.18	1.00	244.29
VC3	141.53	1.01	254.13
VC4	157.65	0.98	324.48
VC5	172.05	1.04	254.38
VC6	151.45	1.45	187.51

Min	**141.53**	**0.98**	**187.51**
Max	**198.78**	**1.45**	**324.48**
AVG	**162.27**	**1.10**	**257.02**
Std. dev.	**20.49**	**0.18**	**44.66**
CV%	**12.63**	**16.05**	**17.38**

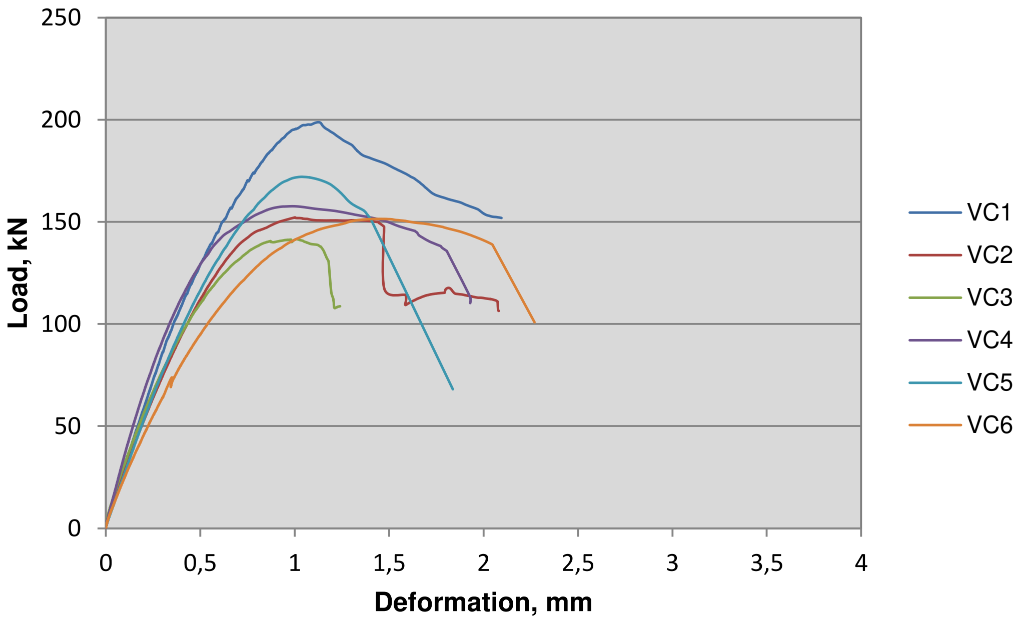


Figure 4. Load-deformation curves for all specimens of Series VC

Table 4 - Test results for Series VCPB

SPECIMEN	P_{ult}, kN	Δ_{Pult}, mm	K, kN/mm
VCPB1	238.84	0.37	888.01
VCPB2	198.99	0.59	483.23
VCPB3	144.11	0.81	359.65
VCPB4	189.39	0.76	457.21
VCPB5	236.43	0.52	596.32
***VCPB6**	229.87	0.44	671.73

Min	**144.11**	**0.37**	**359.65**
Max	**238.84**	**0.81**	**888.01**
AVG	**206.27**	**0.58**	**576.02**
Std. dev.	**36.69**	**0.17**	**187.86**
CV%	**17.79**	**30.01**	**32.61**

*Manufacturing defect: one wood screw missing

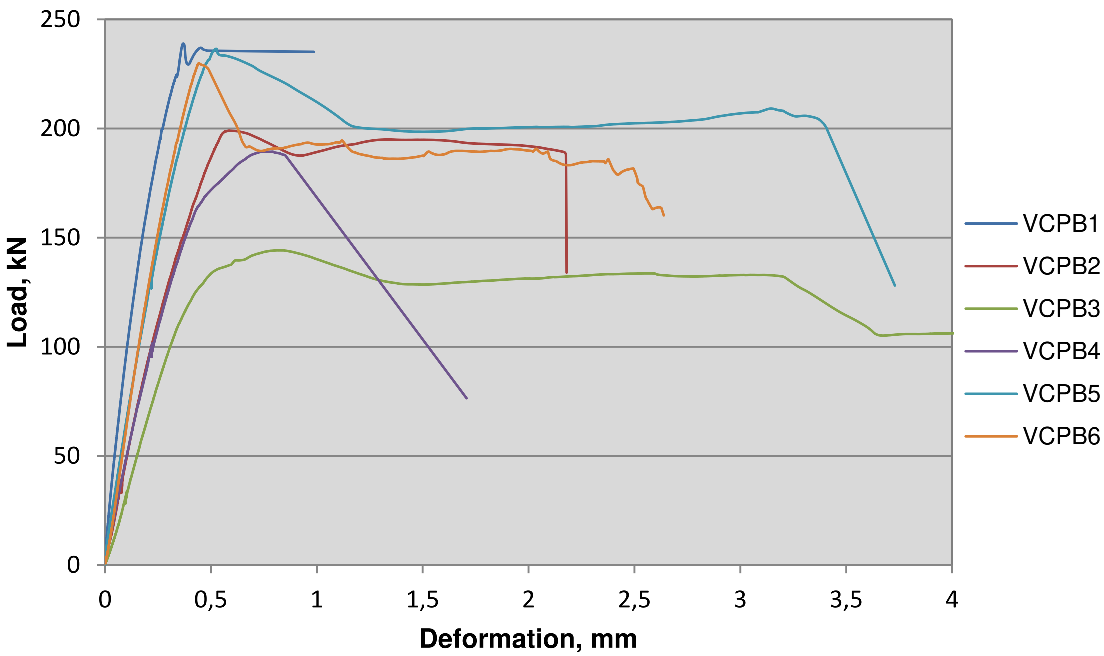


Figure 5. Load-deformation curves for all specimens of Series VCPB

In order to facilitate the assessment of the relative performance of the three (3) assemblies, Figure 6 presents load-deformation curves for every specimen tested in this study superimposed into one graph.

It may be observed that Series VCPB (wood screws and Purbond) had the highest stiffness (**K**) and ultimate loading capacity ($\mathbf{P_{ult}}$) out of the three (3) assemblies.

Series C (common nails and no adhesive) had a significantly lower $\mathbf{P_{ult}}$ and **K**; however it portrayed a much more ductile behavior.

Series VC (wood screws and PL Premium) had a slightly lower $\mathbf{P_{ult}}$ and **K**, however it had a significantly smaller variation (smaller CV%) than Series VCPB.

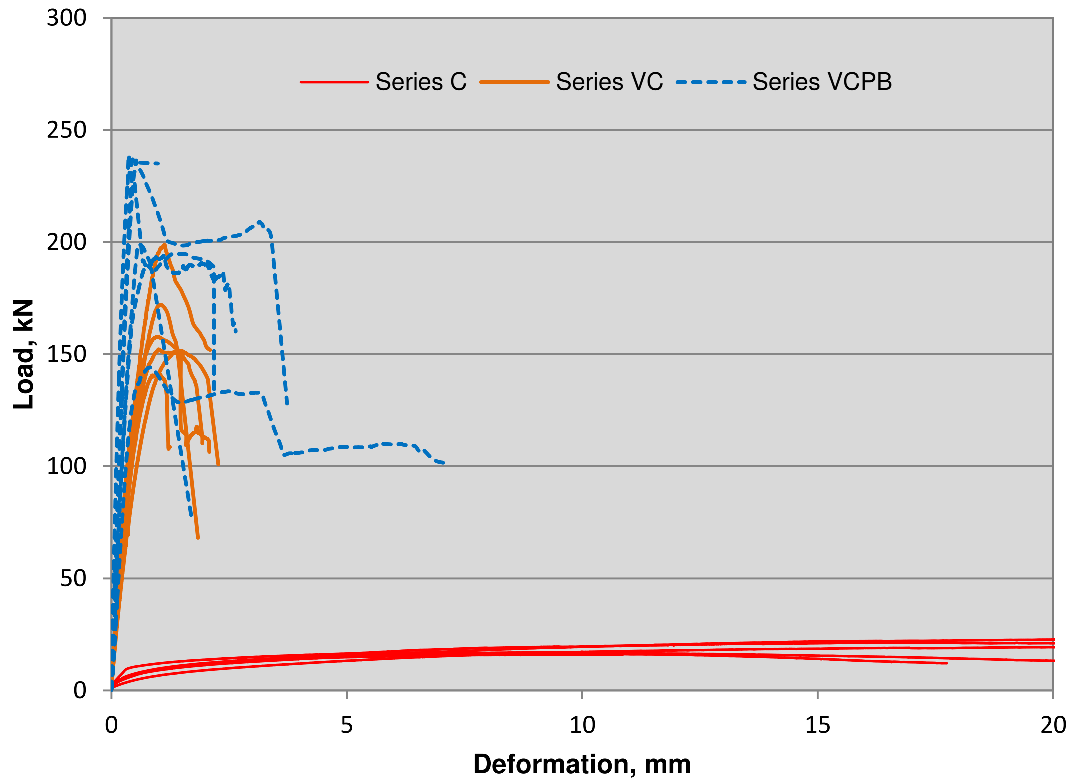


Figure 6. Load-deformation curves for all specimens classed by Series

8.2 Modes of Failure

The dominant failure mode of specimens from Series C was nail bending facilitated by pull through of the nail head in the plywood panel and splitting of the CLT fiber as shown in Figure 7.

Figure 7. Typical mode of failure for specimens of Series C

The dominant mode of failure for specimens of Series VC was failure of the glue line at the first lamination of the plywood panel as seen in Figure 8. This occurred at such an elevated load that following the failure of the glue, the screws failed in shear with limited ductility. No significant bending or pull-through of the screw heads was encountered.

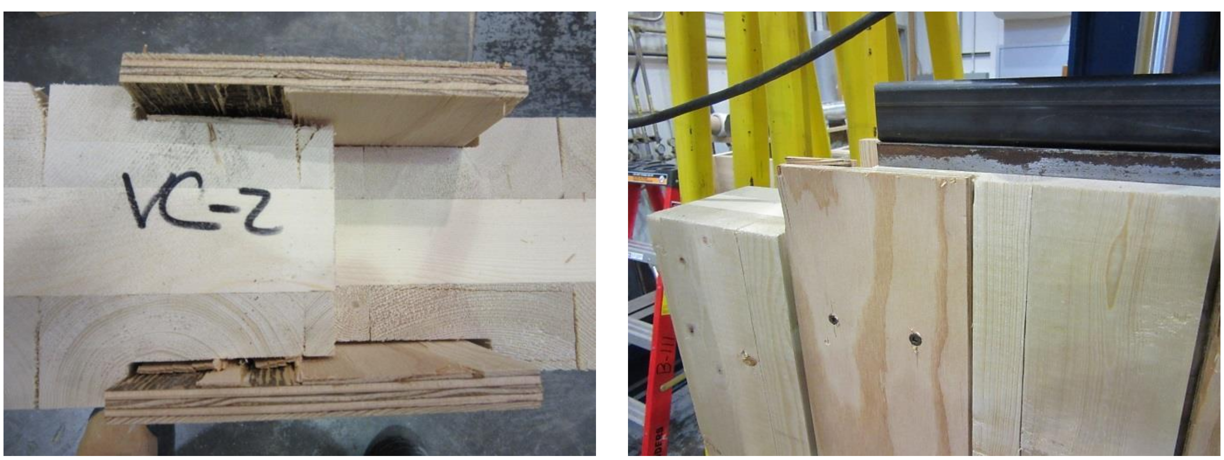


Figure 8. Typical failure mode for specimens of Series VC

The dominant mode of failure for specimens of Series VCPB was failure of the glue line at the first lamination of the plywood panel very similar to what was observed for Series VC. Interestingly, Specimen VCPB6 portrayed a shear failure along the entire thickness of one of the plywood panels as shown in Figure 9. Photographs of the failure modes for every specimen tested are provided in the Appendix I.

Figure 9. Shear through the plywood thickness observed for specimen VCPB 6

9 CONCLUSION

A testing program consisting of three (3) different series of CLT assemblies consisting of six (6) specimens each was performed at FPInnovations' laboratory in Québec City. The objective of the study was to observe the performance of three (3) different systems of connections for CLT panels (Nordic XLAM) submitted to in-plane loading. Testing procedures (monotonic quasi-static) were performed in accordance with the principles of ASTM D 1761-12 Standard Test Methods for Mechanical Fasteners in Wood.

Based on the analyses and observations made during the course of this study, the following conclusions can be made:

- The ultimate load was achieved within a range of 5 to 15 minutes for every specimen tested as specified by ASTM D 1761-12;
- Assembly VCPB (Wood screws and Purbond) portrayed the better performance in terms of both stiffness and ultimate loading capacity;
- Assembly VC (Wood screws and PL Premium) portrayed slightly lower levels of performance in comparison to VCPB, however a reduced variability was noticed;
- Assembly C (common nails and no adhesive) portrayed an ultimate loading capacity nearly ten times smaller than that of VC and VCPB, and a significantly smaller stiffness. However, the failure was significantly ductile in comparison with the two others;
- The failure mode for Assembly C was generally bending of the nails facilitated by pull through at the plywood panels;
- The failure mode for Assemblies VC and VCPB was generally a slip at the glue line of the first lamination of the plywood followed by shear failure of the screws.

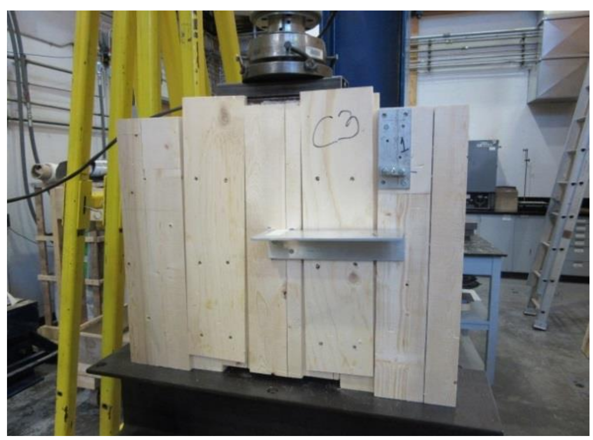
10 REFERENCES

ASTM 2014. Annual Book of ASTM Standards, Volume 04.10 Wood. ASTM, Philadelphia, Pa.

APPENDIX I

Pictures of Series C, Series VC, and Series VCPB

SERIES C – (Common nails – No adhesive)

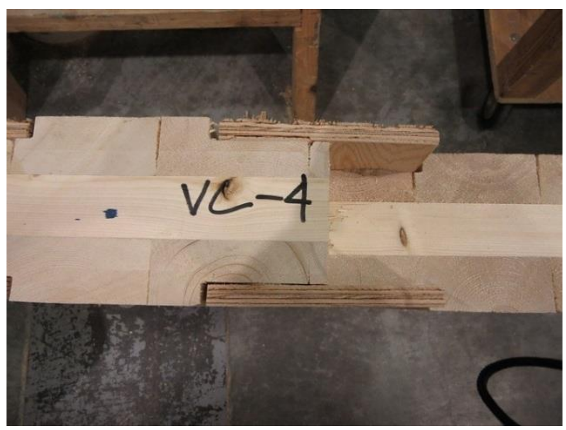



C4


C5


C6

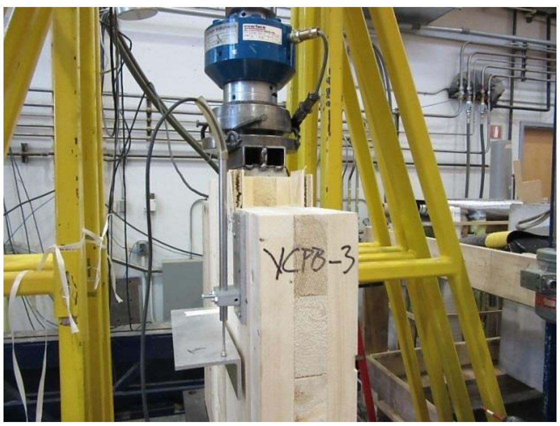
SERIES VC – (Wood screws – PL Premium)




VC-5


VC-6
VC-3
VC-4

SERIES VCPB – (Wood screws – PL Premium)




VCPB-5


VCPB-6


VCPB 6


VCPB-6

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