Ductility of dowelled and nailed CLT and LVL connections under monotonic and cyclic loading

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Abstract

Understanding connection properties, such as strength, stiffness, ductility and overstrength, is critical for structural integrity of timber buildings subjected to seismic loading because connections are the main elements to provide energy dissipation and ductility for timber structures. This paper presents an experimental study on ductility of dowelled and nailed connections in Laminated Veneer Lumber (LVL) and Cross-Laminated Timber (CLT) made out of New Zealand *Radiata pine*. Relatively large dowels (20 mm in diameter) and large nails (4mm x 100mm) as well as steel plates were used to form the connections. Monotonic and quasi-static cyclic tests were performed and the influence of loading protocols on the connection behaviour was investigated. The test results indicated that the dowelled and nailed CLT and LVL connections can be designed with good ductility. For the dowelled connections, the ductility achieved under monotonic loading provided a conservative representation of cyclic ductility. However, for the nailed connections, the monotonic testing significantly overestimated the cyclic ductility. Therefore, it is suggested to evaluate the ductility of nailed connections based on the backbone curve from cyclic loading.

Keywords: dowelled connections, nailed connections, ductility, LVL, CLT, seismic design

1. INTRODUCTION

Ductility and strength are two important properties that quantify a connection's performance. While strength is important to withstand a certain design load, ductility also becomes important in case of overloading such as seismic loading. Connections' plastic deformation capacity provides ductility, while timber member failure is mainly brittle. Connection ductility is hard to predict and often requires experimental testing. Monotonic tests are often used to derive ductility which is then applied in seismic design without assuring that similar ductility can be obtained under cyclic loading. Therefore, it is important to characterise and define connection ductility and compare the performance under both monotonic and cyclic loading.

1.1 Ductility definition under monotonic and cyclic loading

Jorissen and Fragiacomo (2011) presented 12 different ductility definitions including the one commonly used in design codes, as shown in Eq. (1).

$$\mu = \frac{\Delta_u}{\Delta_y} \quad (1)$$

where μ = ductility ratio, Δ_u = ultimate displacement corresponding to the post-peak deformation at 80% of the maximum load, Δ_y = displacement at yield point.
Ductility under cyclic loading is usually defined using the backbone curve of cyclic experiments (Figure 1 right). The backbone curve reflects overall strength and stiffness characteristics under cyclic loading and can be compared against a monotonic load displacement curve (Figure 1 left, Δ_{Fmax} = displacement at maximum load). However, it should be noted that the loading protocol affects strength and stiffness degradation (Figure 1 centre) and can therefore also affect the measured ductility.

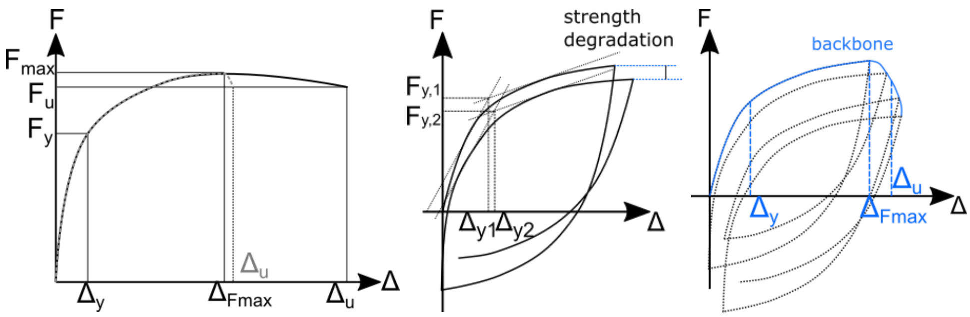

Figure 1: *Monotonic (left), cyclic (centre) load-displacement curve and backbone curve (right) for dowel-type connections*

1.2 Yield point definition and initial stiffness

The yield point definition may highly influence the calculated ductility as well. Different yield point definitions were discussed in detail by Jorissen and Fragiacomo (2011) and the advantages of the 1/6th method (EN 12512) were highlighted (Figure 2 left). However, the initial stiffness K is determined by using the secant between 10% and 40% of F_{max}, which in some cases is sensitive to friction and slip between the timber and steel plates as illustrated in Figure 2 (right): The solid curve's initial stiffness is clearly higher than the one of the dashed curve, however, using a secant they both produce the same initial stiffness K. Therefore, Yasumura (1998) suggested to use the secant stiffness between 10% and 60% F_{max}. This method is suitable for stiff connections such as stocky dowelled connections that have a relatively high yield load. However, for less stiff connections, 60% F_{max} may be located outside the linear elastic zone and produce a misleadingly low value for K. Piazza et al. (2011) suggested to use the Foschi model (1974) for nailed connections which is easier to computerise than the

1/6th method but depends on the displacement domain. In case of nailed and dowelled connections, it was chosen to smooth the load displacement curve by removing the influence of initial slip and friction from the graph and then establishing the initial stiffness by a linear fit between 10% and 40% of F_{max}. While this approach might deliver the most meaningful results, it also requires interpretation and smoothing of the data which is not very viable for automatic data processing.

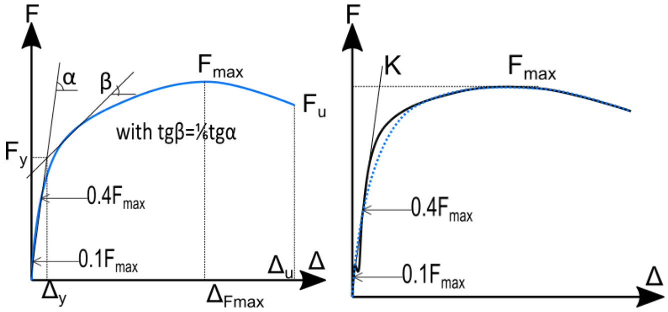

Figure 2: *1/6th method in EN 12512 (left) and initial stiffness K (right)*

1.3 Previous research

Table 1 lists a summary of research conducted on ductility of nailed and dowelled connections loaded parallel to the grain. However, little research has been done to compare ductility obtained under cyclic and monotonic loading.

Table 1: *Summary of previous ductility research, d = diameter [mm], l = nail length [mm], n_1 and n_2 according to Figure 3*

author	connection type	timber	fastener	*d* or *dxl*	layout (n_1xn_2)	loading protocol	ductility
Blaß & Schädle (2011)	slotted-in steel plate	sawn timber	dowel	24	5x1	mono.	1.6
Piazza & Polastri (2011)	double lap timber-to-timber	sawn timber	dowel nail	12/16/20 6xn/a 7xn/a	n/a 2 nails 4 nails	mono.	12–18 21–40
Stehn & Johnsson (2002)	two slotted-in steel plates	Glulam	nail	3.7x97	2x5	cyc.	21.6
Gavric et al. (2014)	hold-down	CLT	nail	4x60	12 nails 9 nails	cyc.	2.76 1.97
Vogt et al. (2014)	hold-down	sawn timber	ring shank nail	4x60	17 nails	mono. & cyc. ISO	3.5 2.4-3.4
Schneider et al. (2015)	hold-downs	CLT	ring shank nail	3.4x76 3.8x60	12 nails 12 nails	cyc. CUREE	5.4 5.6

2. EXPERIMENTS ON DOWELLED CONNECTIONS

2.1 Test set up

In this study, all CLT and LVL specimens were made of *Radiata pine*, 610 mm long, 240 mm wide and had a 20 mm slot to insert a steel plate. The CLT specimens were 130 mm thick with a 35/20/20/20/35 layup without edge gluing. The mean and characteristic densities were $\rho_{mean,CLT}$ = 482 kg/m^3 and $\rho_{k,CLT}$ = 435 kg/m^3, respectively. The average moisture content was 9.9%. The LVL specimens were grade LVL13 (AS/NZS 4357.0:2005). The average moisture content was 8.4% and the mean and characteristic density was $\rho_{mean,LVL}$ = 591 kg/m^3 and $\rho_{k,LVL}$ = 585 kg/m^3, respectively. The LVL specimens were 133 mm thick with the veneers being 2.5 - 4.4 mm thick. The dowels and internal steel plate were made of Grade 300 steel (AS/NZS 4671:2001). The dowel diameter was d = 20 mm and the steel plate was 20 mm thick. The top connection consisted of six d = 25 mm Grade 300 dowels (Figure 3) and was reinforced by self-tapping screws in order to provide significantly higher strength and stiffness than the bottom connection that was designed to produce a ductile failure mode. The same connection layout was used for monotonic and cyclic tests (Table 2). For each loading protocol, five replicates were tested. A loading rate of 1 mm/min was used for the specimens (DT-M) under monotonic loading and 10 mm/min for the specimens (DT-C) under cyclic loading. The cyclic tests followed the ISO loading protocol (ISO 16670:2003) with a target displacement of 5.7 mm for CLT and 7.4 mm. Displacements were measured at 6 locations (front, back, 2 locations on each side) and averaged.

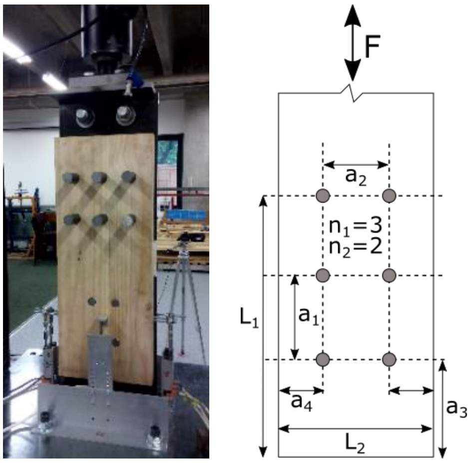

Figure 3: *Set-up for monotonic and cyclic testing (left) and fastener spacing (right)*

Table 2: *Specimen layout*

layout	mm	
a_1	100	*5d*
a_2	60	*3d*
a_3	100	*5d*
a_4	90	*4.5d*

2.2 Test results

Figure 4 displays the load displacement and backbone curves for the monotonic DT-M and cyclic DT-C experiments in LVL and CLT. Figure 5 shows one LVL specimen and one CLT specimen with different failure modes. Tables 3 and 4 show the connection properties: yield strength F_y (calculated following the 1/6th method), maximum load F_{max}, and ultimate load, F_u, and respective displacements, Δ_i, initial stiffness K, and ductility μ, as well as failure mode (B = brittle, D = ductile, M = mixed mode) classified according to Smith et. al (2006).

For the CLT specimens under monotonic loading, two specimens failed in a brittle manner with low ductility although the connection was designed to achieve ductile failure. However, the other eight CLT specimens including those tested under cyclic loading failed in a relatively ductile manner. All of the LVL specimens showed relative good ductility. For the CLT specimens, the average cyclic ductility was 1.15 times larger than the average monotonic ductility. For the LVL specimens, the average cyclic ductility was 1.58 times larger than the average monotonic ductility. Therefore, both CLT and LVL specimens had higher ductility under cyclic loading. This finding is in agreement with Mohammad et al. (1998), who observed increased brittle strength under cyclic loading.

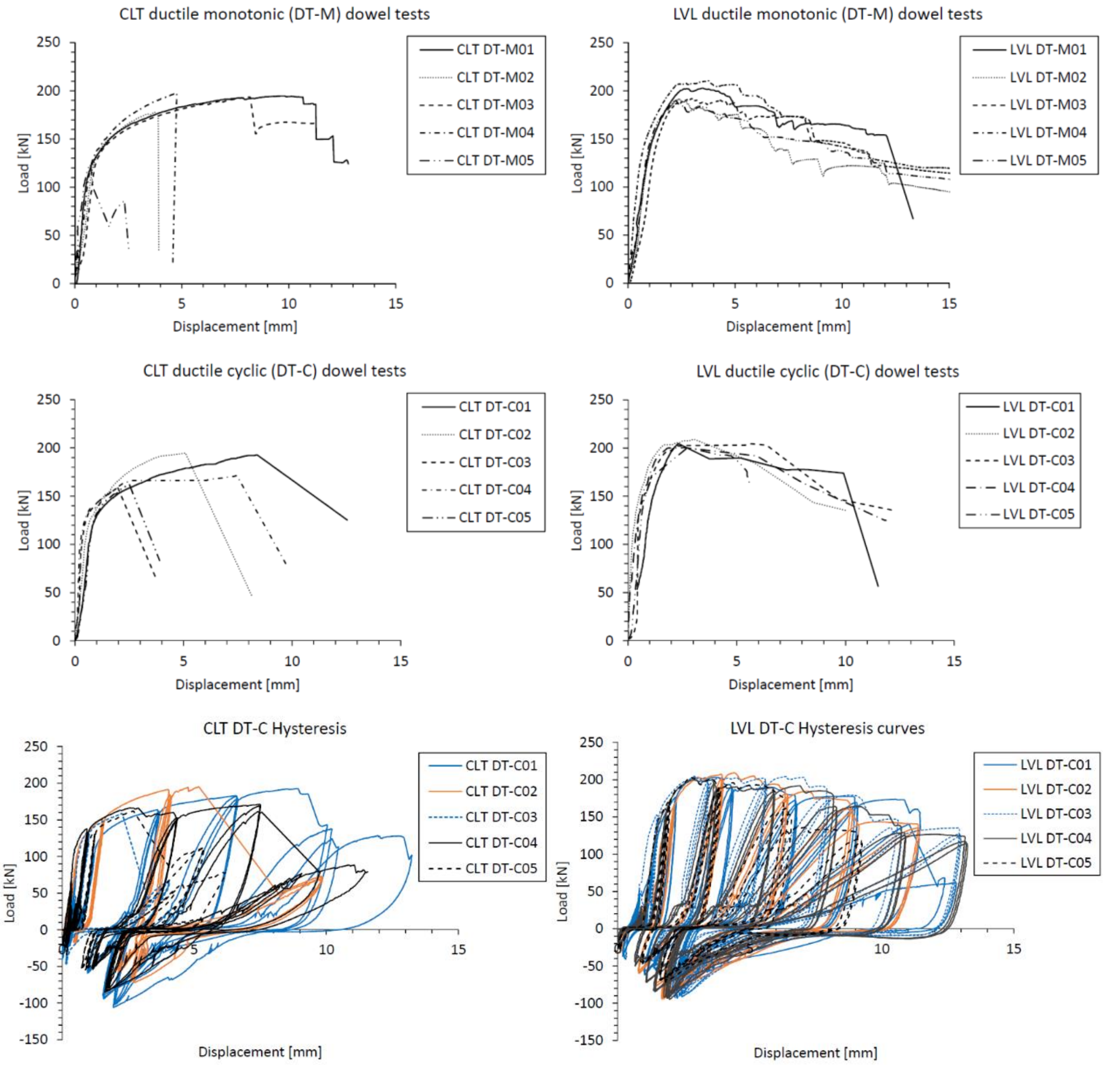

Figure 4: *Load displacement curves from dowel experiments in LVL and CLT*

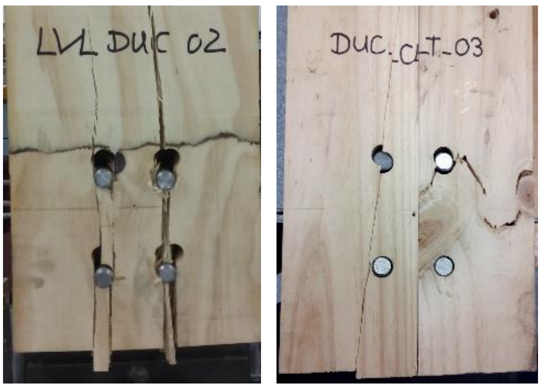

Figure 5: *Secondary row shear in ductile LVL layout (left), and secondary tensile failure in ductile CLT layout (right)*

***Table 3:** CLT ductile DT-M and cyclic DT-C test results*

CLT			DT-M						DT-C			
specimen	1	2	3	4	5	**av.**	1	2	3	4	5	**av.**
F_y [kN]	117	142	135	137	124	**131**	121	125	120	124	134	**125**
F_{max} [kN]	195	178	194	198	124	**178**	193	195	159	171	162	**176**
F_u [kN]	156	178	155	198	99	**157**	154	156	127	137	130	**141**
Δ_y [mm]	0.6	1.2	1.1	0.9	0.7	**0.9**	0.9	0.6	0.5	0.9	1.0	**0.8**
Δ_{Fmax} [mm]	9.5	3.7	8.2	4.8	0.7	**5.4**	8.5	5.1	2.0	7.5	2.4	**5.1**
Δ_u [mm]	10.9	3.7	8.5	4.8	0.8	**5.7**	9.2	5.9	2.4	7.9	3.0	**5.7**
K [kN/mm]	202	121	125	157	177	**157**	138	211	241	134	176	**180**
Energ.Dissip [kN.mm]							4258	1804	477	2866	967	**2074**
Failure mode	D	B	D	M	B	**M**	D	D	M	D	M	**D**
μ	18.8	3.2	7.8	5.5	1.1	**7.3**	10.5	10.0	4.7	8.6	8.2	**8.4**

***Table 4:** LVL ductile DT-M and cyclic DT-C test results*

LVL			DT-M						DT-C			
specimen	1	2	3	4	5	**av.**	1	2	3	4	5	**av.**
F_y [kN]	184	163	184	159	178	**173**	163	167	130	178	158	**159**
F_{max} [kN]	203	192	192	210	190	**197**	205	209	204	200	201	**204**
F_u [kN]	162	153	153	168	152	**158**	164	167	164	160	161	**163**
Δ_y [mm]	1.3	1.1	1.7	0.9	1.3	**1.2**	1.2	0.9	0.6	0.9	0.8	**0.8**
Δ_{Fmax} [mm]	3.5	2.4	3.0	3.8	2.2	**3.0**	2.1	3.0	5.7	2.6	2.0	**3.1**
Δ_u [mm]	7.0	6.5	8.5	8.5	6.3	**7.4**	10.5	7.4	8.7	7.3	5.5	**7.9**
K [kN/mm]	142	148	108	186	137	**144**	141	196	232	198	211	**196**
Energ.Dissip [kN.mm]							5664	5721	6434	7469	3278	**5713**
mode	M	M	M	D	M	**M**	D	D	D	D	D	**D**
μ	5.5	5.9	5.0	10.0	4.9	**6.2**	9.1	8.7	15.5	8.1	7.3	**9.8**

3. EXPERIMENTS ON NAILED CONNECTIONS

3.1 Test set up

The CLT tests comprised of monotonic and cyclic tests with two different nailing patterns: a wide one and a tight one (Figure 6 and Table 5). For each loading protocol, three replicates were tested. The LVL tests only included the tight layout. The displacement rate was also 1 mm/min for the monotonic tests and 10 mm/min for the cyclic tests. Both the CUREE and ISO protocol are suitable for nailed timber connections (Filiatrault et al. 2008), however the CUREE protocol was developed to be less demanding than the ISO protocol (Krawinkler et al. 2000). The target displacement for the ISO protocol is the average u_{Fmax} obtained from monotonic testing and for the CUREE protocol it is 0.6 u_{Fmax}. The CUREE protocol consists of initiation cycles (first 6 cycles) and subsequent primary and trailing cycles. The ISO protocol only contains three primary cycles per cycle group (Figure 7). It was decided to use both loading protocols to compare their influence on the strength and ductility. Displacements were measured on both sides and averaged.

The mean and characteristic densities of the LVL specimens were $\rho_{mean,LVL}$ = 583 kg/m^3 and $\rho_{k,LVL}$ = 578 kg/m^3, respectively. For CLT, the values were $\rho_{mean,CLT}$ = 474 kg/m^3 and $\rho_{k,CLT}$ = 450 kg/m^3. The moisture content was about 10%. The nails were New Zealand made flat head smooth nails with a diameter of d = 4 mm and a length of 100 mm. The side plates were made of Grade 300 steel and 10 mm thick.

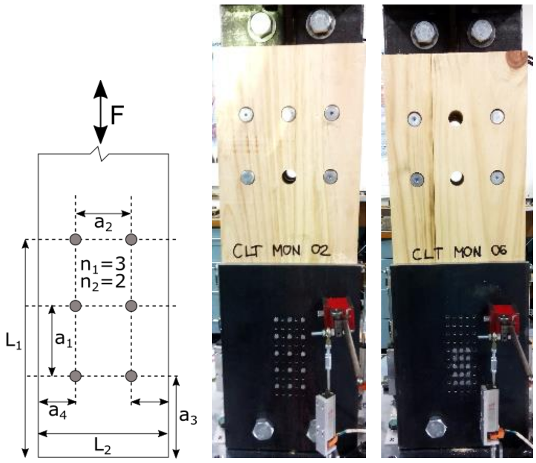

Figure 6: *Fastener spacing (left), wide layout (centre), tight layout (right)*

Table 5: *Nail spacing*

layout	tight		wide	
	mm		mm	
a_1	16	*4d*	32	*8d*
a_2	12	*3d*	24	*6d*
a_3	32	*8d*	32	*8d*
a_4	108	*27d*	96	*24d*
n_1	5		5	
n_2	3		3	

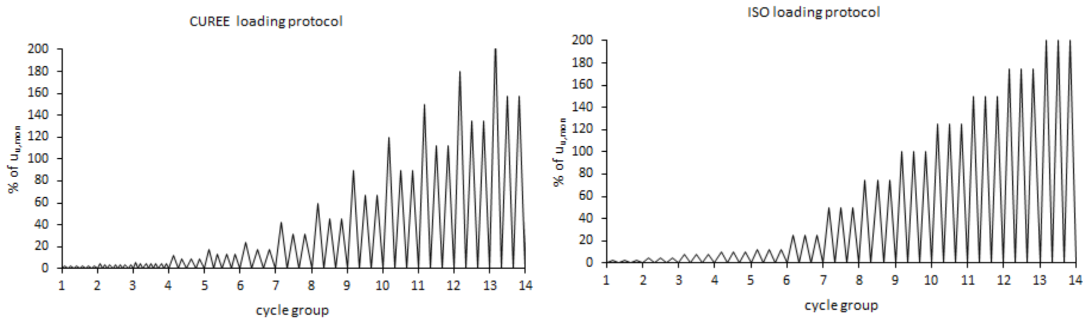

Figure 7: *CUREE (left) and ISO (right) loading protocol*

3.2 Test results

Figure 8 displays the load displacement curves of the connections under monotonic and cyclic loading as well as the backbone curves. Tables 6 and 7 list the connection characteristics calculated following the 1/6th method. Figure 9 shows an example of typical failure modes of the specimens.

The CLT specimens with wide fastener spacing showed embedment and plastic deformation of the nails but ultimately failed in brittle nail fracture (Figure 9, left). The specimens with tight fastener spacing failed in embedment and plastic deformation of the nails and secondary plug shear. Plug shear in itself is a brittle failure mode, however, it was accompanied by nail pull-out and bending which increased ductility. For each connection layout, the average yield, maximum and ultimate load were very similar for all three loading protocols (Table 6). The monotonic tests achieved the highest ductility for both nailing patterns and increased ductility, after reaching peak capacity, with monotonic ductility being 1.2-1.8 times higher than cyclic ductility. The ISO protocol achieved higher ductility than the CUREE protocol for wide nail spacing (Table 6, bottom), but less ductility for the tight nail spacing (Table 6, top).

The LVL specimens were only tested with the tight fastener spacing. Most of the specimens failed in plug shear. There was little difference in average yield strength, F_y, between the specimens under monotonic loading and the specimens under cyclic loading (Table 7). The maximum load F_{max}, was slightly higher (5-7%) for the cyclic protocols, but with little difference between the ISO and the CUREE protocol. On average, the specimens in the monotonic tests showed 21% higher ductility than those tested under cyclic loading.

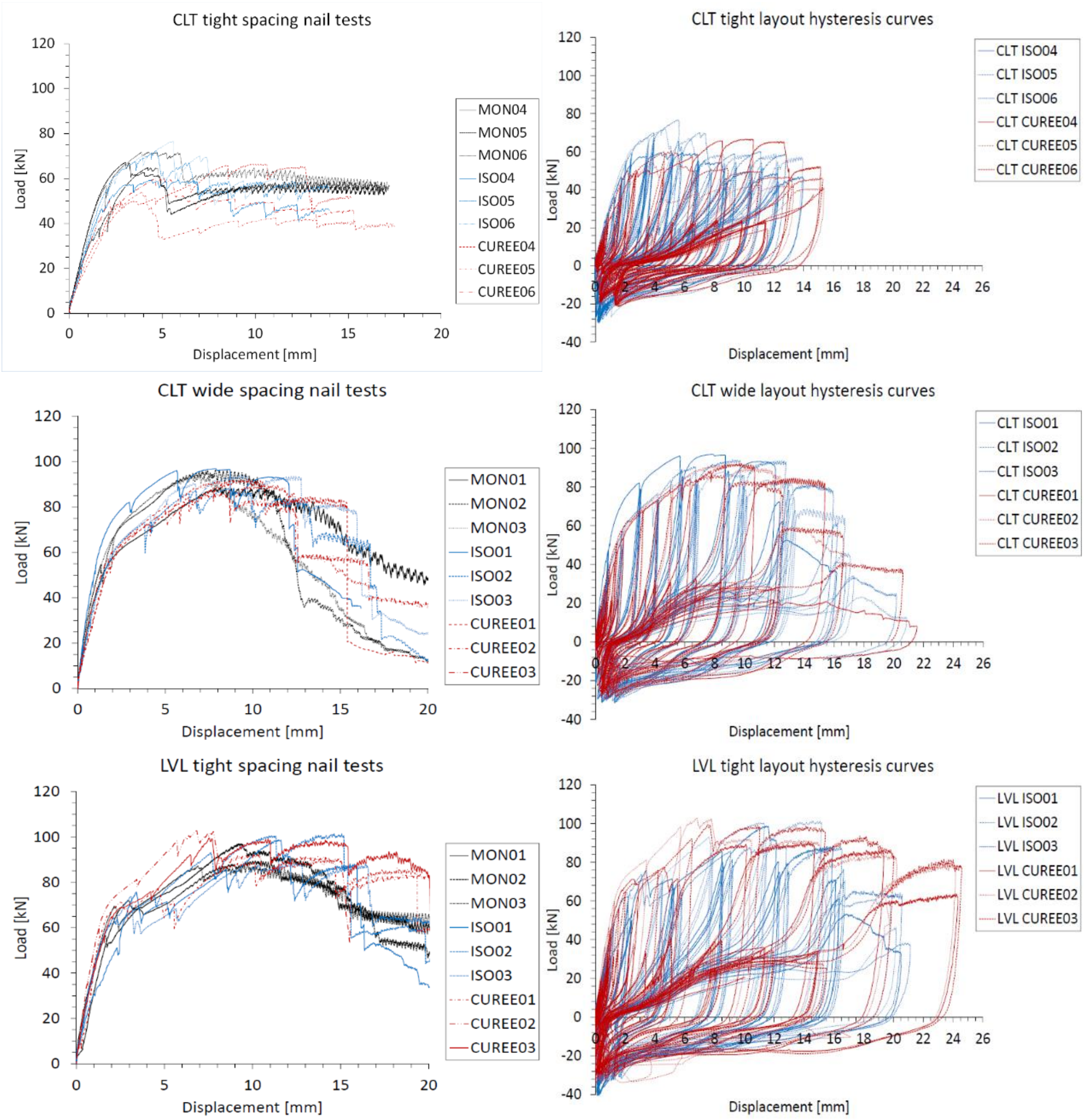

Figure 8: *Load slip curves of nailed LVL and CLT connections*

Figure 9: *Failure modes of nailed connection (left to right): broken nail heads, embedment failure, plug shear, plug shear and nail pull-out*

Table 6: *Test results of nailed CLT connections with wide and tight nailing patterns*

CLT	MON				ISO				CUREE			
Tight spacing	1	2	3	**av.**	1	2	3	**av.**	1	2	3	**av.**
F_y [kN]	56	63	66	**62**	66	60	56	**61**	66	66	56	**63**
F_{max} [kN]	89	96	94	**93**	97	88	94	**93**	92	91	86	**90**
F_u [kN]	71	77	75	**74**	78	70	75	**74**	74	73	69	**72**
Δ_y [mm]	1.3	1.4	1.4	**1.4**	1.1	1.6	1.5	**1.4**	2.3	2.1	1.3	**1.9**
Δ_{Fmax} [mm]	8.2	8.5	6.9	**7.9**	7.9	8.6	9.2	**8.6**	9.8	8.1	8.4	**8.8**
Δ_u [mm]	14.4	11.4	9.7	**11.8**	8.7	9.9	9.7	**9.4**	10.6	8.6	8.7	**9.3**
K [kN/mm]	43.2	46.8	47.0	**45.7**	59.0	37.6	38.8	**43.8**	29.3	32.0	43.1	**33.5**
Energ.Dissip [kN.mm]					3649	2932	3401	**3327**	2671	2060	2621	**2451**
Failure mode	D	D	D	**D**	D	D	D	**D**	M	M	D	**M**
μ	11.1	8.4	6.9	**8.8**	7.7	6.2	6.7	**6.9**	4.7	4.2	6.7	**5.2**
Wide spacing	4	5	6	**av.**	4	5	6	**av.**	4	5	6	**av.**
F_y [kN]	59	55	59	**58**	50	58	62	**57**	39	50	48	**46**
F_{max} [kN]	67	65	72	**68**	59	72	77	**70**	67	54	60	**60**
F_u [kN]	54	52	57	**54**	48	58	61	**56**	53	43	48	**48**
Δ_y [mm]	1.7	2.0	1.7	**1.8**	1.9	1.8	2.1	**1.9**	1.7	2.5	1.7	**2.0**
Δ_{Fmax} [mm]	3.0	4.2	4.3	**3.8**	4.4	4.7	5.6	**4.9**	10.1	3.9	5.1	**6.4**
Δ_u [mm]	5.3	5.2	14.4	**8.3**	5.1	5.1	5.6	**5.3**	10.6	4.7	6.8	**7.3**
K [kN/mm]	36.0	27.7	35.4	**32.7**	26.7	32.4	29.3	**29.4**	23.2	19.8	27.5	**23.0**
Energ.Dissip [kN.mm]					3588	4860	5086	**4511**	3401	2695	3866	**3321**
Failure mode	B	B	D	**M**	B	B	B	**B**	D	B	B	**B**
μ	3.2	2.6	8.6	**4.8**	2.7	2.8	2.7	**2.7**	6.2	1.9	3.9	**4.0**

Table 7: *Test results of nailed LVL connections with tight nailing pattern*

LVL	MON				ISO				CUREE			
tight	1	2	3	**av.**	1	2	3	**av.**	1	2	3	**av.**
F_y [kN]	66	56	56	**59**	65	57	62	**61**	56	62	63	**60**
F_{max} [kN]	89	97	88	**92**	99	101	88	**96**	91	103	100	**98**
F_u [kN]	72	78	70	**73**	79	81	71	**77**	73	82	80	**78**
Δ_y [mm]	1.8	1.4	1.3	**1.5**	2.8	1.4	1.4	**1.9**	1.4	1.2	1.6	**1.4**
Δ_{Fmax} [mm]	9.7	9.2	9.7	**9.6**	11.5	14.6	12.5	**12.9**	14.3	6.8	7.5	**9.5**
Δ_u [mm]	14.9	14.7	15.3	**14.9**	12.1	15.1	12.7	**13.3**	14.6	10.4	10.9	**12.0**
K [kN/mm]	36.7	40.0	43.1	**39.9**	23.5	40.4	44.3	**36.0**	40.0	51.3	39.4	**43.5**
Energ.Dissip [kN.mm]					5761	6104	6087	**5984**	7732	8917	9046	**8565**
Failure mode	D	D	D	**D**	M	D	D	**D**	D	D	D	**D**
μ	8.3	10.5	11.8	**10.2**	4.4	10.8	9.1	**8.1**	10.4	8.7	6.8	**8.7**

4. CONCLUSIONS

In this study, a series of dowelled and nailed CLT and LVL connections were tested under monotonic and cyclic loading to study their ductility and the influence of loading protocols. Steel dowels in a diameter of 20 mm and nail fasteners in a diameter of 4 mm as well as steel plates were used to form the connections. The CLT and LVL specimens were made out of New Zealand *Radiata pine*. Based on the experimental results, it was found that

1) Dowelled and nailed CLT and LVL connections can be designed with good ductility by selecting proper fastener spacing to avoid brittle failure. Combining the monotonic and the cyclic test data, the average ductility ratio was 7.9 for the dowelled CLT connections and 8.0 for the dowelled LVL connections. This ductility is lower than the ductility reported by Piazza et al. (2011) for dowelled timber-to-timber connections. Although it is hard to compare timber-to-timber and steel-to-timber connections, it is likely that ductility can be further improved by increasing the end distance and fastener spacing to prevent mixed mode failure.
2) In case of the tight nailing pattern, the average ductility ratio was 7.0 for the nailed CLT connections and 9.0 for the nailed LVL connections. For the nailed CLT connections with wide nailing pattern, the average ductility decreased significantly to 3.8 due to the premature brittle nail failure. The observed ductility was higher than hold-down ductility reported in literature. However, hold-down geometry is different from the one tested in this study and the hold-downs in literature made use of shorter nails that tended to fail in nail pull-out. Further research is needed to examine the influence of the connection layout and nail diameter-to-length ratio on the ductility and failure mode.
3) For the dowelled CLT and LVL connections, the strength achieved under cyclic loading was similar to the strength achieved under monotonic loading. However, the average ductility ratio achieved under cyclic loading was 36% higher than that achieved under monotonic loading. This is very different from typical observations in timber connections with small fasteners which are able to develop full ductile modes with sufficient fastener yielding and wood embedment deformation. For the dowelled connections tested in this study, large fasteners were used and secondary brittle failure seemed to significantly influence the connection ductility. The test results indicate that monotonic load displacement curves might be used to represent cyclic backbone curves for these types of connections in terms of ductility and strength because monotonic loading seems to provide conservative ductility values. For the CLT connections, it also seems to be beneficial to increase the dowel spacing to avoid brittle failures due to non-edge-glued lamellas. Further study is required to identify optimal layout and dowel spacing for the dowelled CLT connections and to study the influence of mixed failure mode on the ductility property.
4) For the nailed CLT and LVL connections, the strength achieved under cyclic loading was also similar to the strength achieved under monotonic loading. Also, there was no significant difference between the strength and ductility values evaluated under the CUREE protocol and the ISO protocol. However, on average, the ductility value achieved under monotonic loading was 40% higher than that achieved under cyclic loading, which was opposite to the observations in the dowelled connections. In this regard, it seems to be more reasonable to evaluate the ductility of the nailed connections based on cyclic tests rather than monotonic tests.

REFERENCES

Australian/New Zealand Standard, AS/NZS 4357.0:2005 Structural Laminated Veneer Lumber (2005). "Structural Laminated Veneer Lumber." *Standards Australia*, GPO Box 476, Sydney, NSW 2001 and *Standards New Zealand*, Wellington 6140.

Australian/New Zealand Standard, AS/NZS 4671:2001 (2001). "Steel reinforcing materials (2001)." *Standards Australia,* GPO Box 476, Sydney, NSW 2001 and *Standards New Zealand*, Private Bag 2439, Wellington 6140.

Blaß, H. J., & Schädle, P. (2011). "Ductility aspects of reinforced and non-reinforced timber joints." *Engineering Structures*, 33(11), 3018–3026.

European Standard EN 12512 (2013). "Timber structures - Test methods - Cyclic testing of joints made with mechanical fasteners." *European Committee for Standardization* (CEN), Bruxelles.

Filiatrault, A., Wanitkorkul, A., & Constantinou, M. (2008). "Development and Appraisal of a Numerical Cyclic Loading Protocol for Quantifying Building System Performance." *Technical Report MCEER-08-0013,* University at Buffalo, State University of New York

Foschi, R.O. (1974). "Load–slip characteristic of nails". *Wood Science* 7(1):69–76.

Gavric, I., Fragiacomo, M., & Ceccotti, A. (2014). "Cyclic behaviour of typical metal connectors for cross-laminated (CLT) structures." *Materials and Structures*, 1–17.

International Organization for Standardization ISO 16670:2003 (2003). "Timber structures – Joints made with mechanical fasteners – Quasi-static reversed-cyclic test method (2003)." *The international Organization for Standardization*, Genava.

Jorissen, A., Fragiacomo, M. (2011). "General notes on ductility in timber structures." *Engineering Structures*, 33(11), 2987–2997.

Krawinkler, Parisi, F., Ibarra, L., Ayoub, A., and Medina, R. (2000). "Development of a Testing Protocol for Wood Frame Structures," *CUREE Publication No. W-02,* Consortium of Universities for Research in Earthquake Engineering, Richmond, CA.

Mischler, A. (1998). "Design of joints with laterally loaded dowels." *In Proceedings of CIB-W18 meeting Thirty-One,* Savonlinna, (Vol. 31, pp. 1-12).

Mohammad, M., Quenneville, J. H. P., Smith, I. (1998). "Influence of cyclic loads on strength and stiffness of bolted timber connections." *Proceedings of the 5th World Conference on Timber Engineering* Vol. 1, pp. 375-382.

Ottenhaus, L.M., Li, M., Smith, T., Quennevielle, P. (2016). "Ductility and overstrength of dowelled LVL and CLT connections under cyclic loading." *Proceedings of the World Conference on Timber Engineering 2016,* ahead of print, accepted in June 2016.

Piazza, M., Polastri, A., & Tomasi, R. (2011). "Ductility of timber joints under static and cyclic loads." *In Proceedings of the ICE - Structures and Buildings*, 164(2), 79–90.

Smith, I., Asiz, A., Snow, M., Chui, Y. H. (2006). "Possible Canadian / ISO Approach to Deriving Design Values from Test Data." *In Proceedings of the CIB W18 Meeting Thirty-Nine*, Florence.

Stehn, L., & Johnsson, H. (2002). "Ductility Aspects in Nailed Glue Laminated Timber Connection Design." *Journal of Structural Engineering*, 128(3), 382–389.

Yasumura, M. (1998). Mechanical properties of dowel type joints under reversed cyclic lateral loading. *In Proceedings of the CIB-W18 meeting Thirty-One,* (Vol 31. pp. 31-7).