THE CROSS-LAMINATED TIMBER STANDARD IN NORTH AMERICA

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ABSTRACT: The cross-laminated timber (CLT) is a prefabricated solid engineered wood product made of at least three orthogonally bonded layers of solid-sawn lumber or structural composite lumber that are laminated by gluing of longitudinal and transverse layers with structural adhesives to form a solid rectangular-shaped, straight, and plane timber intended for roof, floor, or wall applications. While this engineered wood product has been used in Europe for over 15 years, the production of CLT and design of CLT structural systems have just begun in North America. For the acceptance of new construction materials or systems in North America, such as CLT, a consensus-based product standard is essential to the designers and regulatory bodies. This paper describes and documents the background information and some key issues that were considered during the development of the ANSI/APA PRG 320 *Standard for Performance-Rated Cross Laminated Timber*. This standard is a bi-national standard between the U.S. and Canada, and was developed based on the consensus standard development process of APA–The Engineered Wood Association as a standards developer accredited by the American National Standards Institute (ANSI).

KEYWORDS: Cross-laminated timber, Standard development, Stress classes, ANSI/APA PRG 320

1 INTRODUCTION

Cross Laminated Timber (CLT), as shown in Figure 1, is defined as a prefabricated solid engineered wood product made of at least three orthogonally bonded layers of solid-sawn lumber or structural composite lumber (SCL) that are laminated by gluing of longitudinal and transverse layers with structural adhesives to form a solid rectangular-shaped, straight, and plane timber intended for roof, floor, or wall applications. While this engineered wood product has been used in Europe for over 15 years, the production of CLT and design of CLT structural systems have just begun in North America with some manufacturers currently being in production or in the process of product qualification.

For the acceptance of new construction materials or systems in North America, such as CLT, a consensus-based product standard is essential to the designers and regulatory bodies. In recognition of this need, APA–The Engineered Wood Association in the U.S. and FPInnovations in Canada initiated a joint standard development process in 2010. The intent was to develop a bi-national CLT standard for North America using the consensus standard development process of APA as a standards developer accredited by the American National Standards Institute (ANSI). After 22 months of intensive committee meetings and balloting, the first North American CLT standard was completed as the ANSI/APA PRG 320-2011 *Standard for Performance-Rated Cross Laminated Timber* [1] in December 2011. This paper describes and documents the background information and some key issues that were considered during the development of the ANSI/APA PRG 320 CLT Standard.

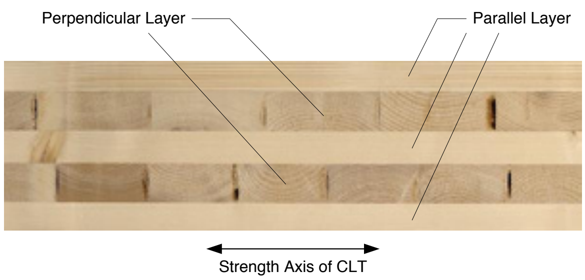

***Figure 1:** Cross-section of a 5-layer CLT panel*

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2 COMPONENT REQUIREMENTS

CLT is manufactured with laminations of lumber or SCL, such as laminated veneer lumber (LVL), laminated strand lumber (LSL) or oriented strand lumber [OSL), which are bonded with structural adhesives through face joint, end joints and/or edge joints. Nail-laminated CLT or other CLT products manufactured without face bonds are outside the scope of ANSI/APA PRG 320.

2.1 LAMINATIONS

ANSI/APA PRG 320 utilizes the European experience in engineering theories and manufacturing processes of CLT, and takes into consideration of the characteristics of the North American lumber resource, manufacturing preference, and end-use expectations. For example, the standard permits the use of any softwood lumber species or species combinations recognized by the American Lumber Standards Committee (ALSC) under PS 20 [2] or the Canadian Lumber Standards Accreditation Board (CLSAB) under CSA O141 [3] with a minimum specific gravity of 0.35, as published in the National Design Specification for Wood Construction [4] (NDS) in the U.S. or CSA O86 [5] in Canada.

The minimum specific gravity of 0.35 is intended as the lower bound for the CLT connection design. This specific gravity represents the near minimum specific gravity of commercially available wood species in North America, Western red cedars (North) in the U.S and Northern species in Canada. To avoid differential mechanical and physical properties of lumber, the standard requires the same lumber species or species combination be used within the same layer of the CLT, while permitting adjacent layers of the CLT to be made of different species or species combinations. The standard also permits the use of SCL when qualified in accordance with ASTM D5456 [6]. In reality, however, it is still years away before SCL would be used in CLT production because of apparent challenges, such as the face bonding of SCL to SCL or SCL to lumber due to the thickness variation of SCL and its cost competitiveness with lumber. Nonetheless, the advantage of SCL that can be produced in a long and wide billet form is an attractive factor that the ANSI/APA PRG 320 Committee elected to include SCL in the standard.

Lumber grades in the parallel and perpendicular layers of CLT are required to be at least 1200f-1.2E MSR or visually graded No. 2, and visually graded No. 3, respectively. Remanufactured lumber is permitted as equivalent to solid-sawn lumber when qualified in accordance with ANSI/AITC A190.1 [7] in the U.S. or SPS 1, 2, 4, or 6 [8,9,10,11] in Canada. Proprietary lumber grades meeting or exceeding the mechanical properties of the lumber grades specified above are permitted provided that they are qualified in accordance with the requirements of an approved agency, which is defined in the standard as an independent inspection agency accredited under ISO/IEC 17020 [12] or an independent testing agency accredited under ISO/IEC 17025 [13] in the U.S., or a certification agency accredited under ISO Guide 65 [14] in Canada. This allows for a great flexibility in the utilization of forest resources in North America.

The net lamination thickness for all CLT layers at the time of gluing is required to be at least 16 mm (5/8 inch), but not thicker than 51 mm (2 inches) to facilitate face bonding. In addition, the lamination thickness is not permitted to vary within the same CLT layer except when it is within the lamination thickness tolerances – at the time of face-bonding, variations in thickness across the width of a lamination is limited to ±0.2 mm (0.008 inch) or less, and the variation in thickness along the length of a lamination is limited to ±0.3 mm (0.012 inch).

The net lamination width is required to be at least 1.75 times the lamination thickness for the parallel layers in the major strength direction of the CLT. This means that if 2x lumber (35 mm or 1-3/8 inches in net thickness after surfacing prior to gluing) is used in the parallel layers, the minimum net lamination width must be at least 61 mm (2.4 inches), i.e., 2x3 lumber. On the other hand, the net lamination width is required to be at least 3.5 times the lamination thickness for the perpendicular layers if the laminations in the perpendicular (cross) layers are not edge-bonded, unless the interlaminar shear strength and creep of the CLT are evaluated by testing. This means that if 2x lumber is used in the perpendicular layers, the net lamination width must be at least 122 mm (4.8 inches), i.e., 2x6 lumber.

This minimum lamination width in the perpendicular layer could become a problem for CLT manufacturers who prefer to use 2x3 (net 38 mm x 63 mm) or 2x4 (net 38 mm x 89 mm) lumber. However, the Committee was concerned about the unbonded edge joints, which could leave gaps that may reduce interlaminar shear strength and encourage excessive creep. Therefore, in this case, the manufacturers will have to either edge-glue the laminations or demonstrate the conformance to the standard by conducting interlaminar shear tests and ASTM D6815 [15] creep tests. It should be noted that this is an interim measure due to the lack of data at this point in time to address the concerns. As a result, it is expected that this provision will be revisited as more information becomes available.

2.2 ADHESIVES

Another critical component for CLT is the adhesives. The standard requires the adhesives used for CLT manufacturing meet the requirements of AITC 405 [16] with the exception that the extreme gluebond durability tests in AITC 405 (either ASTM D3434 [17] or CSA O112.9 [18]), which are designed for adhesive qualification in exterior applications, is not required because CLT products manufactured to ANSI/APA PRG 320 is limited to dry service conditions, such as in most covered structures where the mean equilibrium moisture content of solid-sawn lumber is less than 16% (i.e., 65% relative humidity and 20°C or 68°F). CLT products qualified in accordance with the standard are intended to resist the effects of moisture on structural performance as may occur due to construction delays or other conditions of similar severity.

In Canada, CLT adhesives have to meet the requirements of CSA O112.10 [19] and ASTM D7247 heat durability [20], which is part of the requirements in AITC 405. In addition, in both countries, CLT adhesives have to be evaluated for heat performance in accordance with PS1 [21]. The intent of the heat performance evaluation is to determine if an adhesive will exhibit heat delamination characteristics, which may increase the char rate of the CLT when exposed to fire in certain applications. If heat delamination occurs, the CLT manufacturer is expected to consult with the adhesive manufacturer and the approved agency to develop appropriate strategies in product manufacturing and/or end-use recommendations for the CLT fire design [22].

2.3 LAMINATION JOINTS

Adhesive-bonded edge joints between laminations in the same layer of CLT are not required in accordance with ANSI/APA PRG 320 unless CLT's structural and/or fire performance is qualified based on the use of adhesive-bonded edge joints. As previously mentioned, laminations with unbonded edge joints in the perpendicular layers are subject to the minimum width limitation of 3.5 times the lamination thickness. On the other hand, the end joints within the same lamination, as applicable (e.g., SCL layers may be provided in full width and full length), and the face joints between adjacent laminations must be qualified in accordance with the glulam standard, ANSI/AITC A190.1 in the U.S. and CSA O177 [23] in Canada, with the exception that the interlaminar shear strength criteria do not apply due to the low interlaminar shear strength from cross laminating. However, these provisions will be reviewed when more plant data are gathered and analyzed in the immediate future.

3 CLT REQUIREMENTS

3.1 DIMENSIONS AND DIMENSIONAL TOLERANCES

The thickness of CLT is limited to 508 mm (20 inches) or less in ANSI/APA PRG 320. This is considered an upper limit that the CLT may be handled in production and transportation. In addition, dimension tolerances permitted at the time of manufacturing are as follows:

- Thickness: ± 1.6 mm (1/16 inch) or 2% of the CLT thickness, whichever is greater
- Width: ± 3.2 mm (1/8 inch) of the CLT width
- Length: ± 6.4 mm (1/4 inch) of the CLT length

Textured or other face or edge finishes are permitted to alter the tolerances. However, the designer needs to compensate for any loss in cross-section and/or the specified strength due to such alterations.

The standard also specifies the CLT panel squareness, defined as the length of the two panel face diagonals measured between panel corners, to be within 3.2 mm (1/8 inch) or less. In addition, the CLT panel straightness, defined as the deviation of edges from a straight line between adjacent panel corners, is required to not exceed 1.6 mm (1/16 inch).

3.2 STRESS CLASSES

As part of the standardization effort, seven CLT stress classes are stipulated in ANSI/APA PRG 320, while custom CLT products are also recognized, provided that the products are qualified by an approved agency in accordance with the qualification and mechanical test requirements specified in the standard. The stress classes are presented in the form of structural capacities, such as bending strength (F_bS), bending stiffness (EI), interlaminar shear strength (V_s), and shear rigidity (GA). This allows for the needed flexibility to CLT manufacturers in conformance with the product standard based on the available material resource and required design capacities.

The stress classes were developed based on the following prescriptive lumber species and grades available in North America:

- E1: 1950f-1.7E Spruce-pine-fir MSR lumber in all parallel layers and No. 3 Spruce-pine-fir lumber in all perpendicular layers
- E2: 1650f-1.5E Douglas fir-Larch MSR lumber in all parallel layers and No. 3 Douglas fir-Larch lumber in all perpendicular layers
- E3: 1200f-1.2E Eastern Softwoods, Northern Species, or Western Woods MSR lumber in all parallel layers and No. 3 Eastern Softwoods, Northern Species, or Western Woods lumber in all perpendicular layers
- E4: 1950f-1.7E Southern pine MSR lumber in all parallel layers and No. 3 Southern pine lumber in all perpendicular layers
- V1: No. 2 Douglas fir-Larch lumber in all parallel layers and No. 3 Douglas fir-Larch lumber in all perpendicular layers
- V2: No. 1/No. 2 Spruce-pine-fir lumber in all parallel layers and No. 3 Spruce-pine-fir lumber in all perpendicular layers
- V3: No. 2 Southern pine lumber in all parallel layers and No. 3 Southern pine lumber in all perpendicular layers

The required characteristic strengths and moduli of elasticity for CLT laminations are listed in Table 1. As seen from the list above, both mechanically graded lumber (for "E" classes) and visually graded lumber (for "V" classes) are included in this standard. Also three major species groups in North America, Douglas fir-Larch, Spruce-pine-fir, and Southern pine are all included. With the published lumber properties in the layup, the design capacities of the CLT were derived based on the "shear analogy" model developed in Europe [24] and the following assumptions:

- The modulus of elasticity of lumber in the perpendicular to grain direction, E_{90}, is 1/30 of the

modulus of elasticity of lumber in the parallel to grain direction, E_0
- The modulus of shear rigidity of lumber in the parallel to grain direction, G_0, is 1/16 of the modulus of elasticity of lumber in the parallel to grain direction, E_0
- The modulus of shear rigidity of lumber in the perpendicular to grain direction, G_{90}, is 1/10 of the modulus of shear rigidity of lumber in the parallel to grain direction, G_0

The design capacities are provided in the format of Allowable Stress Design for the U.S. and Limit States Design for Canada, as shown in Tables 2 and 3, respectively. Since Southern Pine is unavailable in Canada, Table 3 does not include CLT Stress Classes E4 and V3. The allowable bending strengths can be readily converted to the characteristic bending strengths (5th percentile with 75% confidence) by multiplying by an adjustment factor of 2.1. The allowable bending stiffness and shear rigidity are based on the mean values and no adjustments are required.

It should be noted that based on the recent full-scale CLT tests for deeper CLT (depths of 7 layers or more), the standard includes a tentative strength reduction factor of 0.85 for the calculated bending strengths in the major strength direction. It remains unclear at this point if such a factor can be attributed to the volume effect. Research is underway to investigate this phenomenon and it will be addressed in the future version of the standard.

Custom CLT classes are permitted in ANSI/APA PRG 320 when accepted by an approved agency in accordance with the qualification and mechanical test requirements specified in the standard. This may include double outer layers or unbalanced layups when clearly identified for installation, as required by the manufacturer and the approved agency. However, the standard requires a unique CLT grade designation be assigned by the approved agency if the custom product represents a significant product volume of the manufacturer to avoid duplication with an existing CLT grade designation that has been assigned to other manufacturers.

3.3 APPEARANCE CLASSIFICATION

There are no mandatory appearance classifications for CLT in ANSI/APA PRG 320. The Committee elected to leave the CLT appearance classifications to be agreed upon between the buyer and seller. However, non-mandatory classifications based largely on selected glulam appearance classifications in ANSI/AITC A190.1 are included in the appendix, which covers the Architectural and Industrial Appearance Classifications. A series of guidelines for the development of a protocol for classifying CLT panels into different appearance classifications based on gaps and checks have been drafted by FPInnovations from research findings [25]. Depending on the market demand, the appearance classifications may be standardized in the future as more CLT products are used in North America.

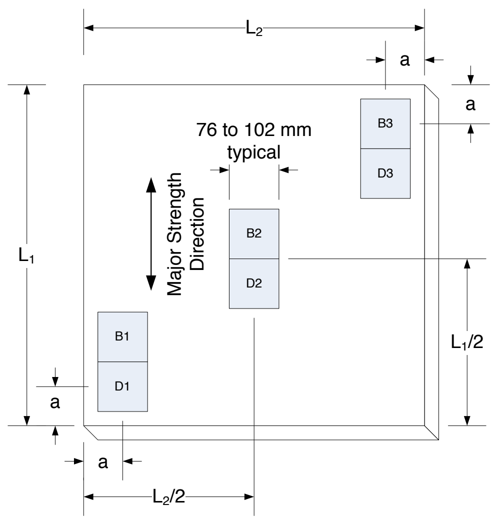
4 QUALIFICATION AND QUALITY ASSURANCE

The standard also stipulates the requirements for plant pre-qualification, structural performance qualification, and quality assurance.

4.1 PLANT PRE-QUALIFICATION

The plant pre-qualification is intended to ensure the CLT plant is qualified for the manufacturing factors, such as the assembly time, lumber moisture content, adhesive spread rate, clamping pressure, and wood surface temperature, prior to the normal production. The plant pre-qualification can be conducted with full-thickness CLT panels of 610 mm (24 inches) or more in the major strength direction and 457 mm (18 inches) or more in the minor strength direction. Two replicated CLT panels are required to be manufactured for pre-qualification for each combination of factors considered. The two replicated CLT panels must not be extracted from a single full-size CLT panel.

The plant pre-qualification includes the evaluation of gluebond (block shear) and durability. Figure 2 shows the locations where the block shear and delamination specimens should be taken for the pre-qualification to ensure the dispersion of the specimens within a sampled CLT qualification panel. Results obtained from the pre-qualification are required to be documented and serve as the basis for manufacturing factors specified in the in-plant manufacturing standard.



a = 102 ± 25 mm; L_1 = 610 to 915 mm; and L_2 = 457 to 915 mm

Figure 2: *Block shear ("B") and delamination ("D") specimen locations*

4.2 CLT STRUCTURAL PERFORMANCE QUALIFICATION

To confirm the major CLT design properties, structural performance tests are required in ANSI/APA PRG 320. The structural performance tests include bending strength, bending stiffness, and interlaminar shear in both major and minor strength directions. The sample size for bending stiffness must be sufficient for estimating the population mean within 5% precision with 75% confidence, or 10 specimens, whichever is greater. The sample size for bending strength and interlaminar shear must be sufficient for estimating the characteristic value with 75% confidence in accordance with ASTM D2915 [26].

The bending tests are required to be conducted flatwise (loads are applied perpendicular to the face layer of CLT) in accordance with the third-point load method of ASTM D198 [27] or ASTM D4761 [28] using the specimen width of not less than 305 mm (12 inches) and the on-center span of approximately 30 times the specimen depth. The Committee considered that a minimum specimen width of 305 mm (12 inches) is necessary to distinguish CLT from typical beam elements. However, it has been reported that for some CLT layups, the use of the span-to-depth ratio of 30 for bending tests in the minor strength direction may result in excessive deflection before the specimen reaches the peak load. Therefore, it is expected that this provision will be revisited in the near future. The weight of the CLT panel is permitted to be included in the determination of the CLT bending strength.

The interlaminar shear tests are required to be conducted flatwise in accordance with the center-point load method of ASTM D198 or ASTM D4761 using the specimen width of not less than 305 mm (12 inches) and the on-center span of 5 to 6 times the specimen depth. The bearing length must be sufficient to avoid bearing failure, but not greater than the specimen depth. All specimens must be cut to length without overhangs, which are known to increase the interlaminar shear strength in shear tests.

4.3 PROCESS CHANGE QUALIFICATION

When process changes occur in production, qualification tests are required, depending on the extent of the changes and their impacts to the CLT performance. ANSI/APA PRG 320 lists some key changes and the required responses, as summarized below:

Process Change	Response
• Press equipment • Adhesive formulation class • Addition or substitution of species from a different species group • Changes to the visual grading rules that reduce the effective bond area or the effectiveness of the applied pressure (e.g., warp permitted)	Plant pre-qualification and Structural re-evaluation
• Other changes to the manufacturing process or component quality not listed above • Adhesive composition (e.g., fillers and extenders)	Plant pre-qualification
• Increase in panel width or length of more than 20%	Structural re-evaluation

4.4 QUALITY ASSURANCE

Quality assurance is required by ANSI/APA PRG 320 to ensure the CLT product quality through detecting changes in properties that may adversely affect the CLT performance. In this regard, an on-going evaluation of the manufacturing process, including end, face, and edge (if used) joints in laminations, effective bonding area, lamination grade limitations, and the finished production inspection, is required to be conducted by the CLT manufacturer to confirm that the product quality remains in satisfactory compliance to the product specification requirements. The production must be held pending results of the quality assurance testing on representative samples. In addition, the product quality assurance must be audited by an independent inspection or certification agency on a regular basis in accordance with the building code requirements.

5 IMPLEMENTATION OF THE STANDARD

In North America, a limited number of CLT production lines have been recently commercialized. Several structures have also been constructed using CLT panels manufactured in North American (see Figures 3 and 4).

Figure 3: *A 4-story CLT apartment building under construction in Quebec, Canada (photo courtesy of Nordic Engineered Wood, Chibougamau, Quebec, Canada)*

However, due to the lack of CLT standards in North America, these structures were generally designed and constructed under an engineer seal, and approved by the regulatory body on a case-by-case basis. With the publication of ANSI/APA PRG 320, it is expected that the acceptance of CLT products will be accelerated. A code change proposal has been submitted by APA to the International Code Council (ICC) for adoption of ANSI/APA PRG 320 into the 2015 International Building Code (IBC) in the U.S. to recognize CLT products, when manufactured in accordance with ANSI/APA PRG 320, as an acceptable construction material in compliance with the code. The CSA O86 Committee in Canada is also evaluating the adoption of CLT into the Canadian code.

***Figure 4:** The Earth Science Building at the University of British Columbia under construction in British Columbia, Canada (photo courtesy of Structurlam, Penticton, BC, Canada)*

It should be noted that ANSI/APA PRG 320 is not a CLT design standard and does not address design-specific issues, such as creep, duration of load, volume effect, moisture effect, lateral load resistance, connections, fire, energy, sound, and floor vibration. Design guides for many of those topics are provided in the CLT Handbook [29] published by FPInnovations in Canada in 2010. A similar effort is being made to develop a CLT Handbook in the U.S. as an interim measure to help designers who are interested in designing CLT structures. In the end, however, the general agreement from the engineered wood products industry is to codify those provisions in a new chapter of the NDS in the U.S. and CSA O86 in Canada. However, this step is likely to take several years to accomplish due to the need for a significant amount of supporting data in North America.

Fortunately, several research projects have been underway through the collaborative efforts by the wood industry, government, and construction, engineering, and research communities under the multi-disciplinary strategic research Network for Engineered Wood-based Building Systems (NewBuilds) in Canada (more information about the activities of NewBuilds can be found at http://www.newbuildscanada.ca/). Built on the knowledge and experience from Europe, it is anticipated that the research results from North America would expedite the completion of the design standards in the NDS and CSA O86.

From a product certification perspective, APA as well as other accredited certification agencies in North America can trademark CLT products in accordance with ANSI/APA PRG 320 to provide the designers with construction materials that are consistent in quality and recognized by the building codes. As a result, the designers can focus on the architectural and structural designs without the concern of material supplies and quality. This is a very significant step toward the wide acceptance of the relatively new construction products, such as CLT, in North America.

6 CONCLUSION

With the publication of the consensus-based CLT standard, ANSI/APA PRG 320, in North America, the engineered wood products industry has taken a very significant step toward the commercialization of the CLT products and systems. A continuing improvement of the standard can be expected for the next few years as more experience is gathered through the production and commercialization processes. This standard, when adopted into national building codes, will recognize the CLT products as construction materials in compliance with the codes and gain wide acceptance by the design and construction industries.

While in the short-term, the CLT products are expected to be designed by engineers or architects experienced in timber engineering, efforts are underway to develop CLT design handbooks and ultimately design standards that will standardize the design requirements, just like other existing engineered wood products in North America. It is believed that the truly collaborative efforts that have been demonstrated by the wood industry, government, and construction, engineering, and research communities throughout the development of ANSI/APA PRG 320 in the last two years will make this a reality at the shortest time possible.

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***Table 1**. Required Characteristic Strengths and Moduli of Elasticity [(a)] for PRG 320 CLT Laminations*

CLT Grades	Laminations in the Major Strength Direction of the CLT						Laminations in the Minor Strength Direction of the CLT			
	$f_{b,0}$ (MPa)	E_0 (MPa)	$f_{t,0}$ (MPa)	$f_{c,0}$ (MPa)	$f_{v,0}$ (MPa)	$f_{s,0}$ (MPa)	$f_{b,90}$ (MPa)	E_{90} (MPa)	$f_{v,90}$ (MPa)	$f_{s,90}$ (MPa)
E1	28.2	11700	19.9	23.6	2.9	0.97	7.2	9000	2.9	0.97
E2	23.9	10300	14.8	22.3	3.9	1.31	7.6	10000	3.9	1.31
E3	17.4	8300	8.7	18.3	2.4	0.79	5.1	6500	2.4	0.79
E4	28.2	11700	19.9	23.6	3.8	1.24	8.3	9600	3.8	1.24
V1	13.0	11000	8.3	17.7	3.9	1.31	7.6	10000	3.9	1.31
V2	12.7	9500	6.5	15.1	2.9	0.97	7.2	9000	2.9	0.97
V3	14.1	11000	8.0	19.0	3.8	1.24	8.3	9600	3.8	1.24

For Imperial: 1 MPa = 145 psi

[(a)] The characteristic values may be obtained from the published allowable design values for lumber in the U.S. as follows:
$f_{b,0}$ = 2.1 x published allowable bending stress (F_b), $f_{t,0}$ = 2.1 x published allowable tensile stress (F_t), $f_{c,0}$ = 1.9 x published allowable compressive stress parallel to grain (F_c), $f_{v,0}$ = 3.15 x published allowable shear stress (F_v), and $f_{s,0}$ = 1/3 x calculated $f_{v,0}$.

***Table 2**. The Allowable Design Capacities [a,b,c] for CLT (for use in the U.S.)*

CLT Grade	CLT Thickness (in.)	Lamination Thickness (in.) in CLT Layup							Major Strength Direction			Minor Strength Direction		
		=	⊥	=	⊥	=	⊥	=	$F_bS_{eff,0}$ (lbf-ft/ft)	$EI_{eff,0}$ (10^6 lbf-in.^{2}/ft)	$GA_{eff,0}$ (10^6 lbf/ft)	$F_bS_{eff,90}$ (lbf-ft/ft)	$EI_{eff,90}$ (10^6 lbf-in.^{2}/ft)	$GA_{eff,90}$ (10^6 lbf/ft)
E1	4 1/8	1 3/8	1 3/8	1 3/8					4,525	115	0.46	160	3.1	0.82
	6 7/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8			10,400	440	0.92	1,370	81	1.4
	9 5/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	18,375	1,089	1.4	3,150	313	1.9
E2	4 1/8	1 3/8	1 3/8	1 3/8					3,825	102	0.53	165	3.6	0.96
	6 7/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8			8,825	389	1.1	1,440	95	1.3
	9 5/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	15,600	963	1.6	3,300	364	1.7
E3	4 1/8	1 3/8	1 3/8	1 3/8					2,800	81	0.35	110	2.3	0.62
	6 7/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8			6,400	311	0.69	955	61	0.98
	9 5/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	11,325	769	1.0	2,210	234	1.4
E4	4 1/8	1 3/8	1 3/8	1 3/8					4,525	115	0.53	180	3.6	0.96
	6 7/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8			10,425	441	1.1	1,570	95	1.4
	9 5/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	18,400	1,090	1.6	3,625	364	2.0
V1	4 1/8	1 3/8	1 3/8	1 3/8					2,090	108	0.53	165	3.6	0.96
	6 7/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8			4,800	415	1.1	1,440	95	1.3
	9 5/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	8,500	1,027	1.6	3,300	364	1.9
V2	4 1/8	1 3/8	1 3/8	1 3/8					2,030	95	0.46	160	3.1	0.82
	6 7/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8			4,675	363	0.91	1,370	81	1.2
	9 5/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	8,275	898	1.4	3,150	312	1.6
V3	4 1/8	1 3/8	1 3/8	1 3/8					2,270	108	0.53	180	3.6	0.96
	6 7/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8			5,200	415	1.1	1,570	95	1.3
	9 5/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	9,200	1,027	1.6	3,625	364	1.9

For SI: 1 in. = 25.4 mm; 1 ft = 304.8 mm; 1 lbf = 4.448 N

(a) This table represents one of many possibilities that the CLT could be manufactured by varying lamination grades, thicknesses, orientations, and layer arrangements in the layup.
(b) Custom CLT grades that are not listed in this table are permitted in accordance with ANSI/APA PRG 320.
(c) The allowable properties can be converted to the characteristic properties by multiplying the tabulated F_bS by 2.1, and EI and GA by 1.0.

***Table 3**. The Limit States Design Capacities [(a,b)] for CLT (for use in Canada)*

CLT Grade	CLT Thickness (mm)	Lamination Thickness (mm) in CLT Layup							Major Strength Direction			Minor Strength Direction		
		=	⊥	=	⊥	=	⊥	=	$f_bS_{eff,0}$ (10^6 N-mm/m)	$EI_{eff,0}$ (10^9 N-mm^2/m)	$GA_{eff,0}$ (10^6 N/m)	$f_bS_{eff,90}$ (10^6 N-mm/m)	$EI_{eff,90}$ (10^9 N-mm^2/m)	$GA_{eff,90}$ (10^6 N/m)
E1	105	35	35	35					42	1,088	7.3	1.4	32	13
	175	35	35	35	35	35			98	4,166	15	12	837	20
	245	35	35	35	35	35	35	35	172	10,306	22	29	3,220	28
E2	105	35	35	35					36	958	8.0	0.94	36	15
	175	35	35	35	35	35			83	3,674	16	8.2	930	18
	245	35	35	35	35	35	35	35	146	9,097	24	19	3,569	26
E3	105	35	35	35					26	772	5.3	0.92	23	9.5
	175	35	35	35	35	35			60	2,956	11	8	605	14
	245	35	35	35	35	35	35	35	106	7,313	16	18	2,325	20
V1	105	35	35	35					15	1,023	8.0	0.94	36	15
	175	35	35	35	35	35			35	3,922	16	8.2	930	20
	245	35	35	35	35	35	35	35	61	9,708	24	19	3,571	27
V2	105	35	35	35					18	884	7.2	1.4	32	13
	175	35	35	35	35	35			41	3,388	14	12	837	17
	245	35	35	35	35	35	35	35	72	8,388	22	29	3,213	23

For Imperial: 1 mm = 0.03937 in.; 1 m = 3.28 ft; 1 N = 0.2248 lbf

[(a)] This table represents one of many possibilities that the CLT could be manufactured by varying lamination grades, thicknesses, orientations, and layer arrangements in the layup.

[(b)] Custom CLT grades that are not listed in this table are permitted in accordance with ANSI/APA PRG 320.