O 37. THE USE OF CROSS LAMINATED TIMBER IN STRUCTURES

Burak Atik[1], Günnur Yavuz[1]

[1]*Konya Technical University, Department of Civil Engineering, Konya, Turkey*

E-mail: burakatik2@gmail.com, gyavuz@ktun.edu.tr

ABSTRACT: Wood has been one of the most preferred building materials because of its durability, accessibility and workability since the first periods that people started to build a shelter. However, wooden structures were substantially left in the early 20th century, and concrete and steel construction systems were begun to be used. Today, the effects of environmental concepts such as sustainability, renewable energy sources, global warming and greenhouse gases on construction production have led to a reconsidering of building materials. Cross-laminated wood (CLT) panels, which have emerged for the last 20 years, enabled the use of the wooden base in multi-storey wood structures. The use of cross-laminated wood as an element of the load-bearing system removes the blind side of wood originating from its orthotropic structure. Poor quality trees are also brought to the sector thanks to these panels created. Sustainable environment could be created by performing tree farming with the purpose of using cross-laminated wood instead of existing tree sources in the construction sector, thus this will be more beneficial economically by minimising the importation of this material. This study provided information about the production stages, areas of usage and environmental features of cross-laminated wood as construction material, and design implementation of this new product as the element of the load-bearing system was carried out. Also, in this study, a multi-layered CLT beam was analysed theoretically in RFEM program as an application of CLT structural member.

Keywords: Cross-laminated timber, multi-storey structures, panel

1. INTRODUCTION

Since the existence of mankind, timber has become the preferred building material in house construction due to its many features such as naturalness, strength, accessibility and processability. In addition, its being economical, healthy and sustainable have enabled to be used widely in places where access to raw materials is easy.

The timber was left in the early 20th century, and concrete and steel structural systems were begun to be used. Stronger, more high-rise buildings and fire resistance may be indicated as the reasons for this. Moreover, the decreasing of the timber compared to the populationin the world and its becoming more expensive have led to the use of alternative materials.

The materials used in constructions have begun to be reconsidered with the emergence of the concepts of sustainability, global warming and renewable energy sources. While 30-40% organic materials were used in the constructionsbefore, this ratio has decreased to 0-10%. The construction industry uses 40% of the world's total energy. The effective component in global warming is carbon dioxide. The timber continuously absorbs carbon dioxide in the air throughout its use in constructions since its growth and prevents its release into the atmosphere (Bostancıoğlu and DüzgünBirer, 2004).

The construction time is shortened due to easy design, manufacture and installation of the timber. It is easy to renew and has high energy efficiency.It is a more insulating material than steel and concrete and is preferred especially in countries with cold climates. What is more, the light weight of the building causes less damage to the building by reducing the load on the building during an earthquake.

2. CROSS LAMINATED TIMBER

The timber material used by drying or without drying after sawn from the log is called solid timber. It consists of solid and pure wood that is not coating and logging. Generally, the new material, which is formed by the combination of timber material such as lumber, chip, fibre and sawdust with binder agents such as glue in different ways in the factory environment, is called industrial material. Industrial timber material has mechanical and technological properties with higher value than solid timber material.

Moreover, it is a high-quality material that does not hold the drawbacks of solid timber material. Industrial timber technology will please consumers by leading tothe more rational use of decreasing forest resources in the world, and provides to achieve products meeting the necessary needs (Güzel and Yesüyev, 2015). While the mechanical properties of the timber are high in parallel with its fibres, these values are not sufficient in the perpendicular direction to the fibres. This weakness caused by the orthotropic structure of the timber is removed by cross-laminated timber elements.

Cross-laminated timber panels,as an industrial timber material, are stiff elements with strong dimensional stability which have been generally glued to each other from their wide surfaces in the manner that the fibre directions of solid wood elements with 3,5,7 or more layers become opposite to each other (generally 90°) and in some cases glued at least 0.6 N/mm² with glue from narrow surfaces (Güzel and Yesüyev, 2015).

Figure 1. CLT concept and CLT panel (Pei, 2013)

2.1. Historical Development

The cross-laminated timber, defined by various abbreviations such as CLT, BSP, KLH and X-lam and known in the world by different names, emerged in Switzerland in the early 1990s. The use of cross-laminated timber technology, developed in Austria with the effort of industry and academic research in 1996, became widespread in the early 2000s. It has become widespread in Europe, America and Canada with the effect of green building approaches and has led to the reorganization of timber building regulations.Nowadays, cross-laminated timber has also begun to be used in multi-storey buildings (Gagnon and Pirvu, 2013).

2.2. Advantages of Cross-Laminated Timber

It significantly increases the segregation resistance of the parts of the CLT by providing a reinforcement effect on the cross-lamination system in the CLT. It ensures two-way mobility similar to the reinforced concrete floor.CLT systems can be easily integrated with steel, reinforced concrete and timber frame structures.

Figure 2. CLT panel with two-way load movement (Brenamann, 2017)

Bearing or non-bearing structural member can be produced from CLT material. Long spans are passed with these panel elements. Even if the panels have window and door openings, they can serve as bearings. They can be used as curtain wall construction elements due to their high axial load bearing capacities and very high floor cutting capacities. Wall panels are highly resistant to dynamic loads. It is 75% lighter than concrete by volume (Landreman, 2017). Its lightness makes the earthquake loads less effective on the construction.

CLT is made indispensable since the panels can be produced in a single piece and the timber material is a natural heat and sound insulation material. It is 15 times more efficient than concrete and 400 times more efficient than steel in terms of thermal efficiency (Waugh, 2018).

Continuity of flooring and panels is ensured by finger joints. Its thin layers provide convenience for determining and correcting the defective parts. Thus, structural defects are at the lowest level.

2.2.1. Fire Resistance of Cross-Laminated Timber

The fire resistance of CLT material was found to be higher than steel and concrete as a result of the tests. CLT panels protect structural capacity for a long time when exposed to fire due to the slow carbonization of timber elements during the fire (Gagnon and Pirvu, 2013).

Increasing the number of layers of panels used as wall, floor and roof elements; increasing layer thickness or covering their surfaces with gypsum enhance their resistance against fire. CLT panel in 7” and with 5 layers was used in ASTM E119 Fire Resistance Test by American Timber Council.It was predicted to resist for 2 hours according to the calculations, but it provided a better result by resisting for 3 hours and 6 minutes. After the tests conducted, CLT material received the necessary approvals for fire resistance (Gagnon and Pirvu, 2013).

2.2.2. Environmental Performance of Cross-Laminated Wood

The cross-laminated timber material has better properties than equivalent concrete and steel constructions in terms of environmental performance. It is renewable, recyclable and recoverable due to the timber used. It generates minimum waste during production processes and their application. The fact that it is a natural material and has a high degree of carbon storage makes it environmentally friendly.

2.3. Production Steps of Cross-Laminated Timber

Appropriatelumber is selected for CLT, and the strength of thislumber is checked. Lumber is grouped according to the productive lengths and widths that can be obtained. Planing process is applied to the surfaces to ensure the smoothness of the surfaces. The lengths are cut in equal lengths to form the panels. Glue is applied to the surfaces for the second layer following the first layer formed in horizontal position, and the joint process is performed by compressing the second layer vertically. Panels are packaged by opening door and window openings in accordance with the project measurements, thus it is made ready for transport.

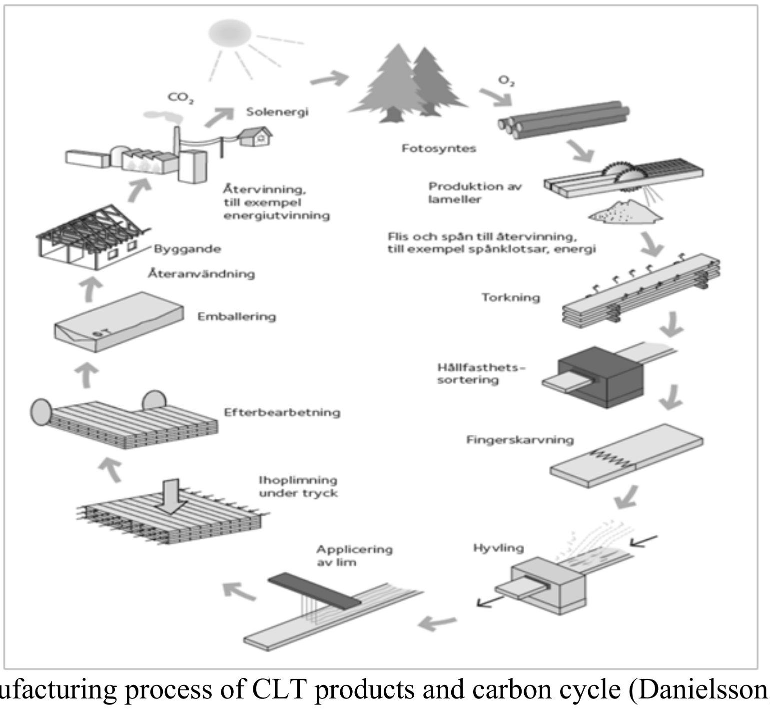


Figure 3. The manufacturing process of CLT products and carbon cycle (Danielsson, 2017)

2.4. Standards

The current ANSI/APA PRG-320 (Standard for Performance-Rated CLT) product standard is used for mechanical properties and product performance of CLT material in the USA and Canada. This standard includes panel measurements, tolerances, component requirements, construction performance requirements and qualities. NDS(National Design Specification) and IBC (International Building Code) standards are used in constructional design in the USA and Canada.The NDS contains the required calculations for the design, limitations, joint material calculations. Some limitations have been given to the design in the IBC.

3. LOADING IN CROSS LAMINATED TIMBER PANELS

Wall and floor elements bear the load in CLT constructions.Producing panels as a single piece and finger joints in providing the continuity enable to pass long spans. Deflection calculation is made in the middle of the span in CLT floors as in reinforced concrete floor. Since deflection is a critical condition for floors, it is a factor to be consideredin dimensioning CLT floors.In order to reduce deflection, the thickness or the number of layers is increased.

The strong axis trying to bend during the loading is called the major axis, and the axis trying to segregate is called the minor axis.While the strength values of the layers on the major axis are higher, this value is much less on the minor axis, and is often not included in the calculations.

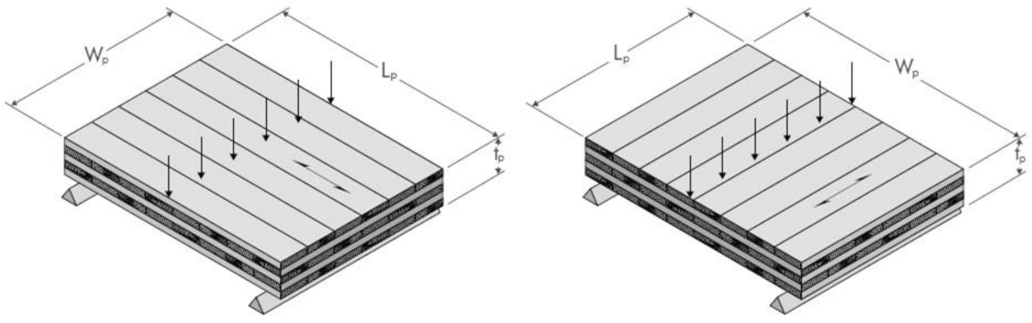
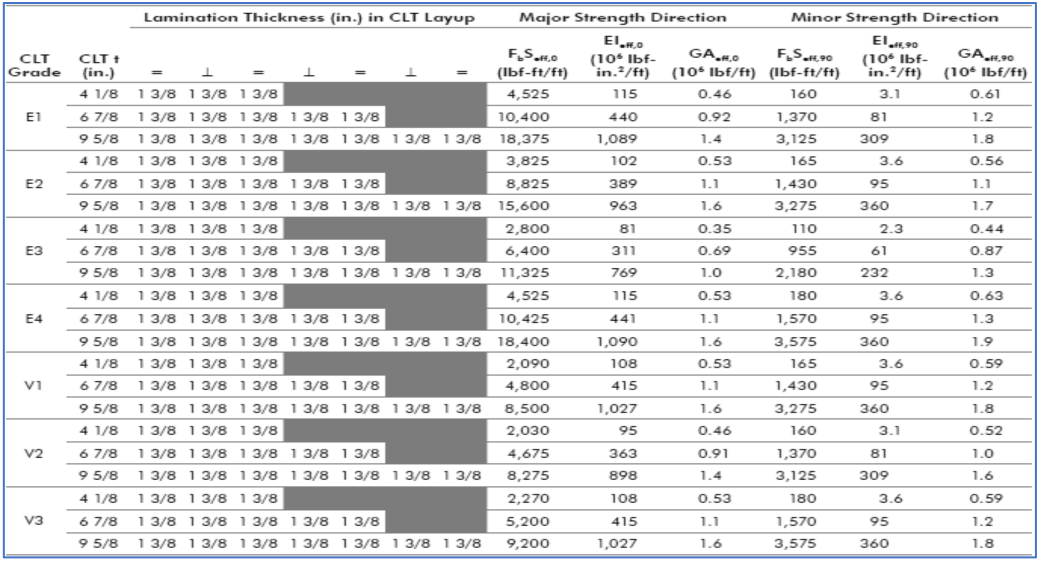


Figure 4. Loadings on major and minor bending axes (ANSI/APA PRG-320, 2018)

The major and minor axes of the layers vary in different directions in a two-way operating floor. The strength values used in the calculation for these directions are provided by the CLT manufacturer.These values are given in Table 1 of PRG-320 for the USA and Canada.

Table 1. ASD reference design values for CLT (ANSI/APA, PRG-320 Table A2.)



		Lamination Thickness (in.) in CLT Layup							Major Strength Direction			Minor Strength Direction		
CLT Grade	CLT t (in.)	=	⊥	=	⊥	=	⊥	=	$F_bS_{eff,0}$ (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	0.61
	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	1.2
	9 5/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	18,375	1,089	1.4	3,125	309	1.8
E2	4 1/8	1 3/8	1 3/8	1 3/8					3,825	102	0.53	165	3.6	0.56
	6 7/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8			8,825	389	1.1	1,430	95	1.1
	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	3,275	360	1.7
E3	4 1/8	1 3/8	1 3/8	1 3/8					2,800	81	0.35	110	2.3	0.44
	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	0.87
	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	2,180	232	1.3
E4	4 1/8	1 3/8	1 3/8	1 3/8					4,525	115	0.53	180	3.6	0.63
	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	1.3
	9 5/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	18,400	1,090	1.6	3,575	360	1.9
V1	4 1/8	1 3/8	1 3/8	1 3/8					2,090	108	0.53	165	3.6	0.59
	6 7/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8			4,800	415	1.1	1,430	95	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	8,500	1,027	1.6	3,275	360	1.8
V2	4 1/8	1 3/8	1 3/8	1 3/8					2,030	95	0.46	160	3.1	0.52
	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	1.0
	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	3,125	309	1.6
V3	4 1/8	1 3/8	1 3/8	1 3/8					2,270	108	0.53	180	3.6	0.59
	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	1.2
	9 5/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	9,200	1,027	1.6	3,575	360	1.8

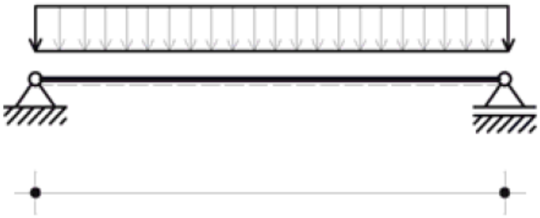
4. DEFLECTION CALCULATION OF FLOOR SYSTEMS

In this study, deflection calculation was analysed with the help of manual solution and RFEM (version 5.18) program for a simply supported cross-laminated timber floor, and the results were compared.

4.1. Analysis According to Elastic Method

The deflection calculation is carried out with simply supported beam logic in CLT floor coverings. The solution is applied for a width of 1 ft at the selected span. Equations required for deflection are obtained from the NDS 2018 Standard used in structural design. Strength values are taken for the selected section from PRG-320. These values are bending and shear stiffness values. The deflection value to be performed by the floor is found with the strength values involved in the equations.The obtained values are compared with the limit values valid for CLT in IBC 2018 to determine the conformity of the section.

Deflection values were calculated for a simply supported beam made of CLT. The 5-layer V1 section was selected from the PRG-320 as the CLT material and the total thickness of the layers used in this section was 6 7/8 inches (174.625 mm). The floor had an 18 ft (5.49 m) span. The design loads weregiven as follows: Dead Load = 50 psf (2.39 kN/m²), Live Load = 60 psf (2.87 kN/m^2).



Fi or

The strength values for the section in the thickness of V1 6.875 were obtained as bending stiffness above from PRG-320 Table 1, $EI_{eff} = 415x10^6\ lbf.in^2/ft$ and shear stiffness $GA_{eff} = 1.1x10^6\ lbf/ft$. The shear deformation coefficient was accepted as 11.5 for one end simply supported in a uniform loading from K_s NDS 2018 Table 10.4.1.1.

$$EI_{app} = \frac{EI_{eff}}{1+\frac{K_S EI_{eff}}{GA_{eff}}} = \frac{415x10^6}{1+\frac{11.5x415x10^6}{1.1x10^6(18x12)^2}} = 379{,}69x10^6 lb.in^2/ft \qquad (1)$$

$$\Delta_{max} = \frac{5}{384}\frac{wL^4}{EI_{app}} = \frac{5}{384}\frac{(\frac{60}{12})(18x12)^4}{379.63x10^6} = 0.373\ in. \qquad (2)$$

The critical limiting state in floor members for IBC 2018 is experienced in the live loading of CLT floor members. The deflection limit for the live loading from IBC table 1604.3 should be smaller or equal to L/360.

Required deflection condition was met for the beam member when the control was performed for the critical conditions of $\Delta_{max} = 0.372\ in\ (9.45\ mm). < \frac{18x12}{360} = 0.6\ in\ (15.24\ mm)$.

4.2. RFEM Analysis Results

In the RFEM (version 5.18) linear finite element analysis program, structural analysis of the considered beam shown in Figure 6 was performed. Analysis for NDS 2018 standard was conducted in live loading by selecting V1 6 7/8" CLT section for 18 ft(5486 mm) beam span. Maximum deflection values and the stress distribution on the beam obtained as a result of the analysis are shown in Figure 7 and 8, respectively. Accordingly, the maximum vertical displacement in the midspan of the beam was determined to be 0.372 in. (9.45 mm). This value was obtained as 0.3% different from the deflection valuecalculated according to the elastic method. The maximum stress values obtained in different layers as a result of the analysis are shown Figure 9.

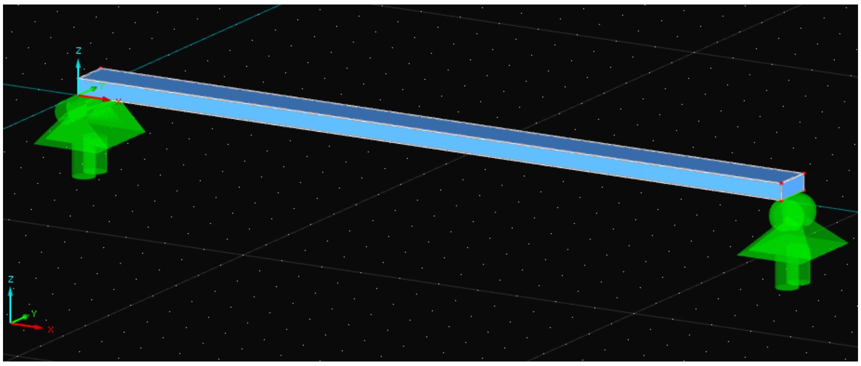


Figure 6. Simply supported beam modelingin RFEM 5.18 program

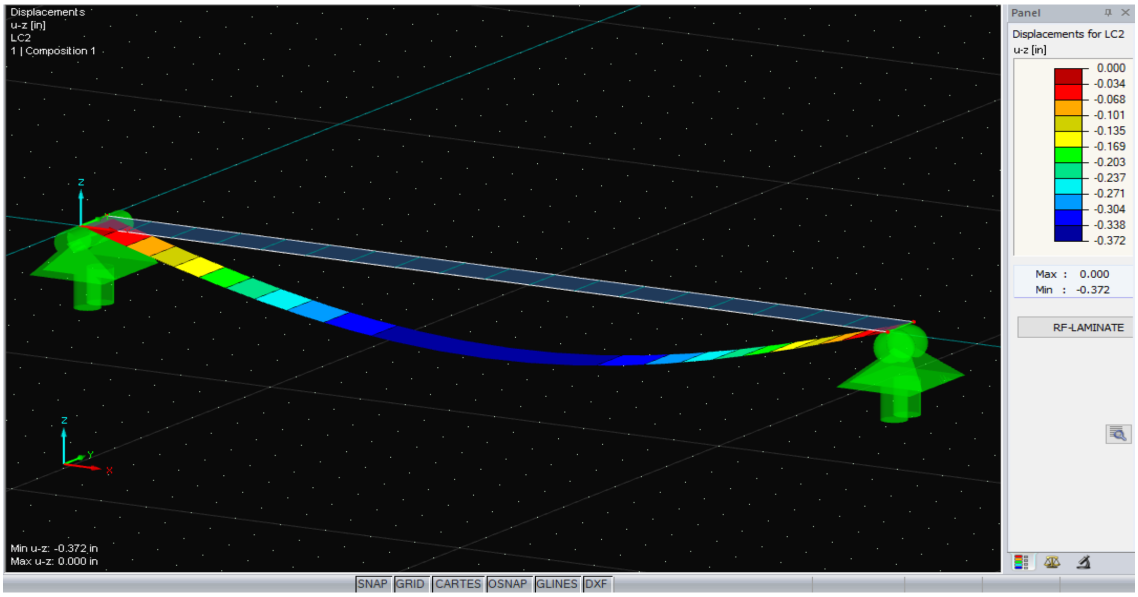


Figure 7. Deflection valuesof simply supported beam

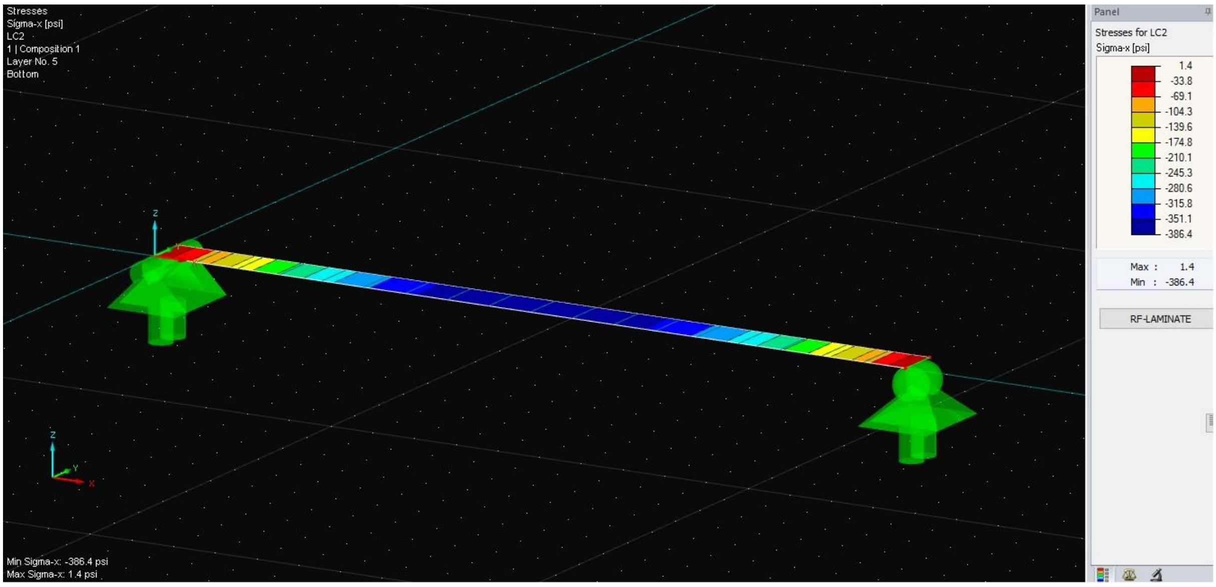
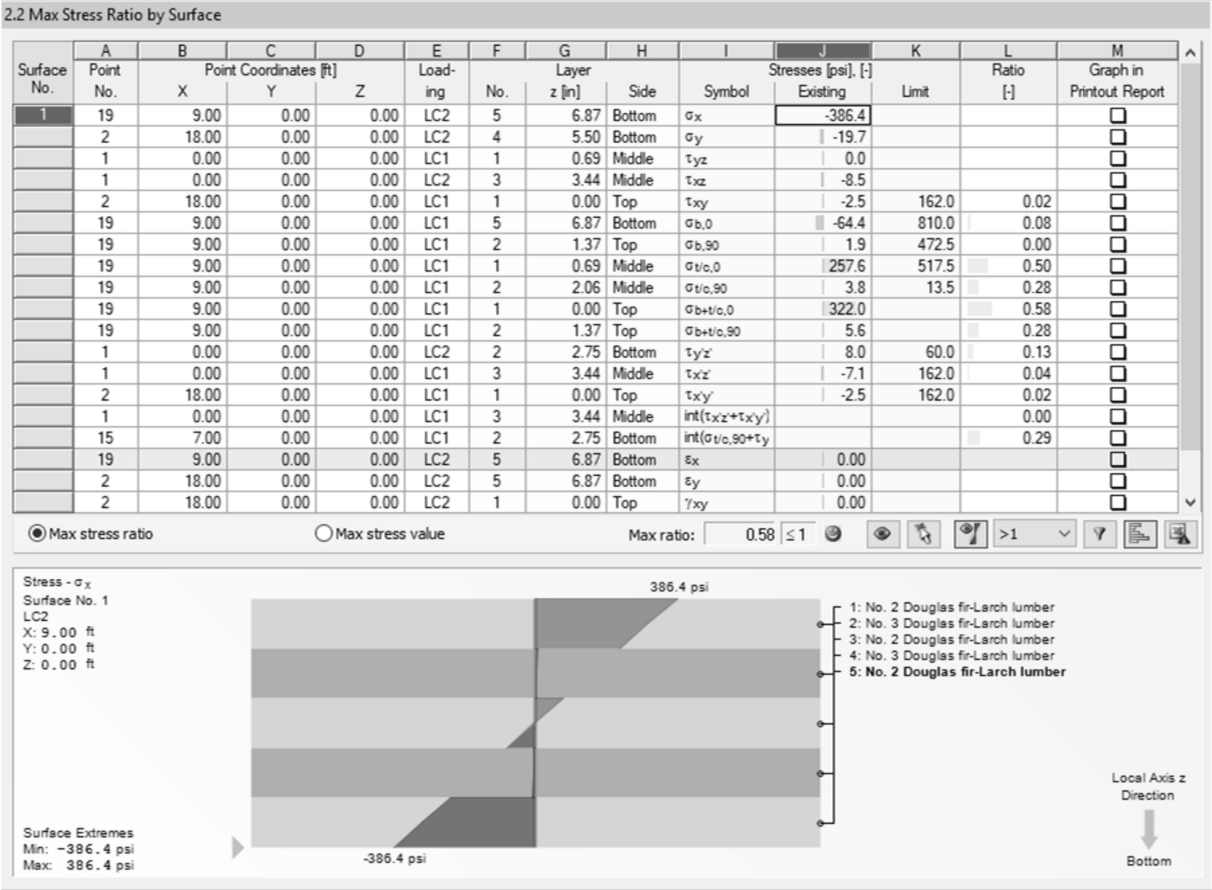


Figure 8. Stress distribution on simply supported beam



2.2 Max Stress Ratio by Surface

Surface No.	A Point No.	B Point Coordinates [ft] X	C Y	D Z	E Load-ing	F Layer No.	G z [in]	H Side	I Stresses [psi], [-] Symbol	J Existing	K Limit	L Ratio [-]	M Graph in Printout Report
1	19	9.00	0.00	0.00	LC2	5	6.87	Bottom	σ_x	-386.4			☐
	2	18.00	0.00	0.00	LC2	4	5.50	Bottom	σ_y	-19.7			☐
	1	0.00	0.00	0.00	LC1	1	0.69	Middle	τ_{yz}	0.0			☐
	1	0.00	0.00	0.00	LC2	3	3.44	Middle	τ_{xz}	-8.5			☐
	2	18.00	0.00	0.00	LC1	1	0.00	Top	τ_{xy}	-2.5	162.0	0.02	☐
	19	9.00	0.00	0.00	LC1	5	6.87	Bottom	$\sigma_{b,0}$	-64.4	810.0	0.08	☐
	19	9.00	0.00	0.00	LC1	2	1.37	Top	$\sigma_{b,90}$	1.9	472.5	0.00	☐
	19	9.00	0.00	0.00	LC1	1	0.69	Middle	$\sigma_{t/c,0}$	257.6	517.5	0.50	☐
	19	9.00	0.00	0.00	LC1	2	2.06	Middle	$\sigma_{t/c,90}$	3.8	13.5	0.28	☐
	19	9.00	0.00	0.00	LC1	1	0.00	Top	$\sigma_{b+t/c,0}$	322.0		0.58	☐
	19	9.00	0.00	0.00	LC1	2	1.37	Top	$\sigma_{b+t/c,90}$	5.6		0.28	☐
	1	0.00	0.00	0.00	LC2	2	2.75	Bottom	$\tau_{y'z'}$	8.0	60.0	0.13	☐
	1	0.00	0.00	0.00	LC1	3	3.44	Middle	$\tau_{x'z'}$	-7.1	162.0	0.04	☐
	2	18.00	0.00	0.00	LC1	1	0.00	Top	$\tau_{x'y'}$	-2.5	162.0	0.02	☐
	1	0.00	0.00	0.00	LC1	3	3.44	Middle	int($\tau_{x'z'}+\tau_{x'y'}$)			0.00	☐
	15	7.00	0.00	0.00	LC1	2	2.75	Bottom	int($\sigma_{t/c,90}+\tau_y$			0.29	☐
	19	9.00	0.00	0.00	LC2	5	6.87	Bottom	ε_x	0.00			☐
	2	18.00	0.00	0.00	LC2	5	6.87	Bottom	ε_y	0.00			☐
	2	18.00	0.00	0.00	LC2	1	0.00	Top	γ_{xy}	0.00			☐

● Max stress ratio ○ Max stress value Max ratio: 0.58 ≤1

Stress - σ_x
Surface No. 1
LC2
X: 9.00 ft
Y: 0.00 ft
Z: 0.00 ft

Surface Extremes
Min: −386.4 psi
Max: 386.4 psi

Figure 9. Stress values obtained as a result of analysis and maximum stress ratio

5. CONCLUSIONS

Cross-lamination structurally eliminates the weaknesses of the timber.The cross-laminated timber material has enabled the use of timber bearing systems in multi-storey constructions with its high strength, stability and stiffness. It minimizes the earthquake loads affecting the construction due to its being light in multi-storey buildings. Timber offers environmentally friendly solutions by storing carbon into its structure.

In this study, the mid-span deflection of a multi-layered CLT beam was analysed theoretically.The deflection value was obtained as 0.372 in(9.45 mm) for the considered beam mid-span using the PRG-320, NDS 2018 and IBC 2018 standards.The results were confirmed by founding the same displacement value as a result of static analysis in RFEM program carried out. What is more, surface stresses were determined in RFEM program, the highest value was found to be 386.4 psi(2.66MPa) in the middle of the span. The ratio of maximum stress value to bearing stress strength was found to be 0.58.

REFERENCES

National Design Specification (NDS) for Wood Construction ASD/LFRD, 2018, American Wood Council, AWC, Lesburg, VA.

ANSI/APA PRG320, 2018, "Standard for Performance-Rated Cross-Laminated Timber", APA- The Engineered Wood Association.

Bostancıoğlu E., DüzgünBirer E., 2004, "Ekolojive Ahşap-Türkiye'deAhşapMalzemeninGeleceği", UludağÜniversitesiMühendislikMimarlıkFakültesiDergisi, Bursa, Cilt 9, Sayı 2, sayfa: 37-44.

Brenemann, S., 2017, Guide to citing Internet sources [online], Washington, "https://www.woodworks.org/wp-content/uploads/17DS04-BRENEMAN-Structural-CLT-Floor-and-Roof-Design-WSF-171004.pdf" [ZiyaretTarihi: 17 Şubat 2019]

Danielsson, H., 2017, Guide to citing Internet sources [online], Lund, Lund University, "http://www.kstr.lth.se/fileadmin/kstr/pdf_files/Timber_Engineering_2017/CLT_-_design_and_use_new.pdf" [ZiyaretTarihi: 22 Mart 2019]
Dlubal-company, 2018, RFEM 5.18 Tiefenbach, Germany.
Gagnon S., Pirvu C., 2013, Cross Laminated Timber (CLT) Handbook, FPInnovations, Vancouvar, BC, Canada,1-12.
Güzel N., Yesügey S., 2015, "ÇaprazLamineAhşap (CLT) MalzemeileÇokKatlıAhşapYapılar", MimarlıkDergisi, Ankara, Sayı 382.
International Building Code (IBC), 2018, International Code Council, Washington DC.
Landreman A., 2017, "Introducing Cross Laminated Timber", The Wood Products Couincil, Wisconsin, US, 38.
Pei, S., 2013, "https://ascelibrary.org/doi/abs/10.1061/%28ASCE%29AE.1943-5568.0000117" [ZiyaretTarihi: 28 Mart 2019]
Waugh Thistleton Architects, 2018, 100 Projects UK CLT, Canada, 68-70.