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Dynamic characteristics of CLT panels: computer modelling and simulations

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Dynamic characteristics of CLT panels: computer modelling and simulations

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Abstract. The fundamental vibration frequency and deflections due to the unit static force of the cross-laminated timber panels of different heights and spans were calculated. The calculation of the effective flexural rigidity was performed by the Gamma method. Obtained values are compared with the values obtained by modeling the construction in the Ansys software package. Three types of floor panels were analyzed with the same combinations of layer thicknesses in the cross section, but with different number of layers. The panels are 4, 5 and 6 meters long and 1 meter wide. Based on the results, recommendations have been made in accordance with current criteria that define the acceptable behavior of lightweight floor structures in relation to vibrations caused by human action.

1. Introduction

Cross laminated timber (CLT) is a modern product that greatly improved the physical properties of traditional wood as building material [1]. CLT is made of controlled dried wooden elements – layers of uniform width, free of defects (knots, resin etc.). By removing all of the defects and cross-gluing the layers it is possible to produce the material that has more uniform mechanical properties than the traditional wood.

A CLT cross section contains a minimum of three cross-glued layers, but most often five or seven. Alternate layers are mutually perpendicular; however, it is possible to double certain layers so that greater strength can be achieved in a desired direction.

Today the use of CLT in multi-family houses is increasing and there is a need to develop better performing CLT floors in order to increase the comfort of the residents. Floor vibration is significant problem for these structures. Because they are light and flexible, vibration is a source of discomfort in the use of this floor systems and its major cause are dynamic movements produced by human activities, such as walking.

This paper deals with numerical analysis of dynamic behaviour of CLT floor structures. Advantages and possible shortcomings will be pointed out.



2. Serviceability limit state of vibration

Vibration of timber floors is a problem of serviceability limit state which refers to discomfort from the aspect of use, at loads that regularly exist in everyday use of the structure.

The feeling of discomfort when vibrating is individual and varies from person to person. It is well known that vibrations that are disturbing to one person may not be to another. This makes it very difficult to determine the threshold of human acceptability. The standards and literature find various proposed criteria that a timber floors must satisfy in designing to ensure its acceptable behavior due to dynamic loading, the most commonly used combination is the criterion of the minimum value of the fundamental frequency and the criterion of the maximum allowable deflection due to unit static forces, CLT Handbook [2], which is:

$$\frac{f}{d^{0.7}} \geq 13 \quad \text{or} \quad d \leq \frac{f^{1.43}}{39} \quad (1)$$

where:

f - fundamental frequency (Hz),

d - maximum deflection due to static force $F = 1 \text{ kN}$ (mm).

3. Materials and methods

The effective stiffness, fundamental frequencies and maximum deflection due to static force for three simply supported floor CLT panels were analyzed. Spans were varied from 4.0 m to 6.0 m. The height of the panel is varied from 9.8 cm to 22.6cm depending on number of the layers in the cross section of the panel (figure 1).

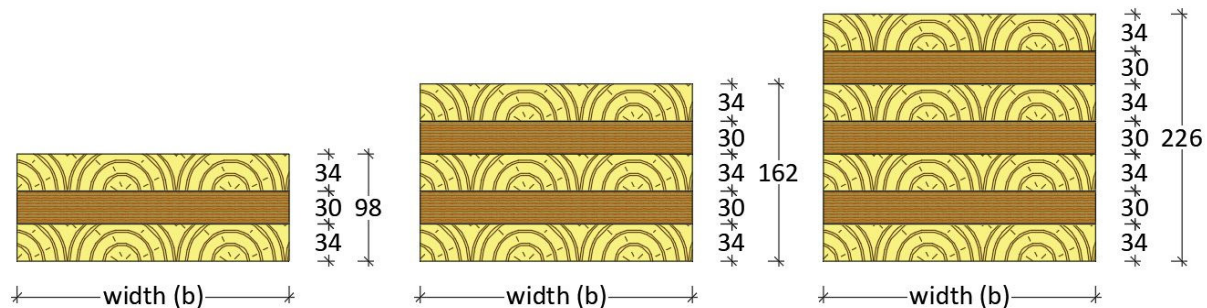


Figure 1. Geometric characteristics of the CLT panels FP1, FP2 and FP3.

The mechanical characteristics of the longitudinal and lateral layers of the timber floors are shown in table 1. The shear of the longitudinal layers is neglected because the ratio of the span to the height of the CLT panels is greater than 30 [2]. The effective stiffness is calculated by the Gamma method [3] and the mean density for C24 wood class is 420 kg/m^3 and for C18 is 380 kg/m^3 .

Table 1. Mechanical properties of the longitudinal and lateral layers.

Layers	Strength classes	f_m (MPa)	E_0 (MPa)	E_{90} (MPa)	G_0 (MPa)	G_R (MPa)
Longitudinal	C24	24	11000	370	690	69
Lateral	C18	18	9000	300	560	56

The fundamental frequency of a simply supported timber floor can be calculated analytically using the equation:

$$f = \frac{\pi}{2l^2} \sqrt{\frac{(EI)_{ef}}{\gamma A}} \quad (2)$$

where: l - span of timber floor (m); $(EI)_{ef}$ - effective panel stiffness 1.0 m wide in the direction of span (Nm^2); γ - volume of wood (kg/m^3); A - area of the cross section (m^2).

The maximum deflection due to the unit static force expressed in mm can be determined by the following equation:

$$d = \frac{1000Pl^3}{48(EI)_{ef}} \quad (3)$$

where: $P = 1000 \text{ N}$.

The finite element method was applied using Ansys 14.0 computer software. The timber floor is modeled as a 2D laminate model consisting of layers, which represent the third dimension of the model. Construction modeling was performed using elements from the Ansys library. A 4-node two-dimensional element SHELL181 was selected. It was used as a 2D element which thickness is defined with the stacking sequence of the layers. An element is defined by four nodes and six degrees of freedom in each node, three translations and three rotations. The basic input data for this element are: modulus of elasticity, Poisson's ratio (coefficient) and volume of wood. The finite element is $0.125 \times 0.25 \text{ m}$ in size (figure 2). The adopted mesh was determined by an iterative procedure, until the results of two successive steps differed by less than 1%.

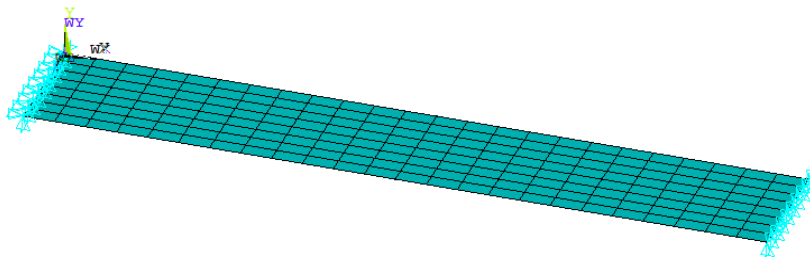


Figure 2. Arrangement of nodes and finite elements of the CLT panel FP1 with 4,0 m span.

4. Results and discussion

The floor fundamental frequency and the maximum deflection due to the unit static force are calculated according the CLT Handbook [2]. Figure 3 shows the first vibrational shape of the CLT panel with 4.0 m span. The results are shown in table 2, 3 and 4. Also, the corresponding limiting values are given.

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ANSYS
OCT 2 2019
16:27:04

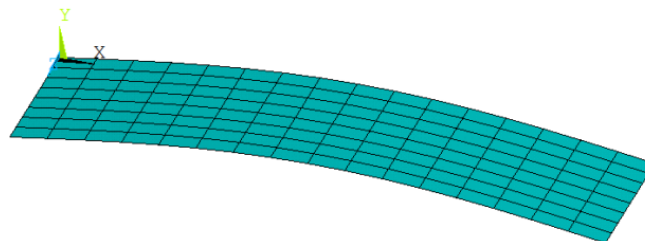


Figure 3. First characteristic mode shape of CLT panel FP1 with 4.0 m span.

Table 2. The fundamental frequency of the CLT panels.

CLT		$f_{min} = 10 \text{ Hz}$ [4]		
		The fundamental frequency f (Hz)		
		$l = 4.0 \text{ m}$	$l = 5.0 \text{ m}$	$l = 6.0 \text{ m}$
FP1	Analytical	12.70	8.22	5.74
	Ansys	12.79	8.26	5.76
FP2	Analytical	18.74	12.23	8.58
	Ansys	18.79	12.27	8.61
FP3	Analytical	24.91	16.28	11.42
	Ansys	23.98	15.87	11.23

Table 3. The unit point load deflection of the CLT panels.

CLT		$d_{max} \leq 1.15 \text{ mm}$ [4]	$d_{max} \leq 1.01 \text{ mm}$ [4]	$d_{max} \leq 0.82 \text{ mm}$ [4]
		The unit point load deflection		
		$l = 4.0 \text{ m}$	$l = 5.0 \text{ m}$	$l = 5.0 \text{ m}$
FP1	Analytical	1.69	3.23	5.52
	Ansys	1.70	3.27	5.54
FP2	Analytical	0.47	0.88	1.49
	Ansys	0.48	0.89	1.51
FP3	Analytical	0.19	0.36	0.60
	Ansys	0.21	0.38	0.62

Table 4. Combined design criterion.

CLT		$\frac{f}{d^{0.7}} \geq 13$		
		Combined design criterion		
		$l = 4.0 \text{ m}$	$l = 5.0 \text{ m}$	$l = 6.0 \text{ m}$
FP1	Analytical	8.80	3.62	1.74
	Ansys	8.82	3.60	1.74
FP2	Analytical	31.79	13.37	6.49
	Ansys	31.41	13.31	6.45
FP3	Analytical	79.66	33.28	16.33
	Ansys	71.50	31.24	15.69

The results in tables 2 and 3 show a decrease in the value of the fundamental frequency of the CLT panel with increasing its span, while its value changes significantly with the change in the number of layers in the cross section. The modal analysis in the Ansys software package confirmed the analytically obtained values, which indicates very high precision of the analytical expressions.

If the value of 10 Hz was adopted for the required minimum fundamental frequency of the light floor structure, which corresponds to the more stringent recommendations in the available literature, CLT panels of type FP1 with spans 5.0 m and 6.0 m would not be acceptable from the standpoint of serviceability limit state, as well as panels of type FP2 with span 6.0 m. But if the value of 8 Hz [5, 6]

was accepted as the minimum required fundamental frequency of CLT panels, spans of the FP1 panel could range up to 5.0 m, and for FP2 panels even 6.0 m.

However, the criterion of maximum allowed deflection due to the unit static force and combined design criterion whose results are shown in table 3 and 4 are much stricter when evaluating the dynamic acceptability of CLT floor panels. According to these criteria, only FP3 panels would not cause discomfort to the user in their daily activities, regardless of the span tested. FP2 type panels meet the prescribed requirement for the span of 4.0 m and 5.0 m, while FP1 type panels do not meet the prescribed requirement in any tested case.

It is evident that the increase in the number of layers placed in the longitudinal direction significantly affects the dynamic behavior of the panels as the values of the criteria change with their heights, and it is difficult to assess whether or not the structure satisfies based only on one parameter.

5. Conclusions

The presented results of the analyzed floor CLT panels show that they can be very successfully applied in the floor structures of residential and commercial buildings, provided that an adequate dynamic calculation is carried out. The combined design criterion and the unit point load deflection limit are significantly stricter compared to the fundamental frequency limit therefore it is advisable to use multiple recommendations and guidelines when evaluating the acceptability of a structure from a dynamic point of view.

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