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METHOD OF CALCULATION OF PANEL BUILDINGS FROM CROSS-LAMINATED TIMBER

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Abstract. Building constructions made of cross-laminated timber become more and more widespread. Experience in the timber structures design and operation for various purposes confirms the feasibility of their use. Recently, the construction of prefabricated cross-laminated timber houses has become especially widespread. The problem solution of cross-laminated timber panels calculation by means of a finite element method with the material`s reduced mechanical characteristics application is offered in this article. The specified formulas for definition of the reduced geometrical and mechanical characteristics of cross-laminated timber panels` various types, including those made of combined cross-laminated timber, are resulted. The algorithm of cross-laminated timber panels calculation by means of a finite element method is resulted. The possibility of using flat finite elements taking into account orthotropic properties for the calculation of cross-laminated timber panels using the elasticity above modulus according to the above method, adjusting the Poisson's ratios so as to preserve the condition of elastic potential in timber, is reasoned.

Keywords: cross-laminated timber, panel building, calculation scheme, finite element method, stress-strain state, soil base-foundation-above-ground structure system.

Introduction. Experience in the timber structures design and operation for various purposes confirms the feasibility of their use [1]. Recently, the timber multi-storey buildings construction with the use of laminated timber panels has become especially widespread, what is facilitated by the fact that such construction is 5-20% cheaper than similar houses with metal or reinforced concrete, including prefabricated reinforced concrete panels. This is facilitated by the use of simpler tools in the construction, and the panels theFEMlves have less weight, which affects the more economical foundations design and reduces costs during installation and transportation. Prefabricated timber multi-storey buildings have also performed better than their analogues made of steel and reinforced concrete under the action of seismic loads.

Cross-laminated timber (CLT) is made by gluing an odd number of boards layers with a mutually perpendicular arrangement of wood fibers. The development of CLT panels began in 1974, when E. Cziesielski [2] first proposed the design of the coating in the form of a multilayer slab made of boards. other technological openings.

If necessary, CLT panels are made with holes in the places of windows, doors and other technological openings installation. The thicknesses of the boards of the longitudinal and transverse layers can be the same or different. The main requirements for the manufacture, test methods and determination of CLT panels strength classes are contained in [3, 4].

CLT panels are used as load-bearing walls, slabs and floors in low- and multi-storey buildings of various purposes [5, 6, 7].

Literature review. There is almost no domestic experience in the use of CLT panels in housing construction. Launched in Ukraine in Korosten, the production of CLT panels had little effect on their widespread use, which is significantly affected by the lack of domestic regulations on the calculation and design of both individual panels and buildings made of them as a whole. In the latest editions of normative documents of the European Union (Eurocode-5 or EN 1995-1-1: 2008 [8]), Ukraine (DBN B.2.6-161: 2017 [9]), Russia (SP 64.13330: 2017 [10]) and Belarus (TKP 45-5.05-146-2009 [11]) there are no guidelines for the design and calculation of structures using CLT panels. Exceptions are Austrian national regulations (ÖNORM B 1995-1-1 [12]) and German (DIN EN 1995-1-1 / NA: 2010-12 [13]). From all the above we can conclude that there is an urgent need to develop rules for the design of CLT panels and buildings using them, taking into account the peculiarities of national design traditions, climatic features, raw material base of timber, traditions of knot construction.

Well-known European scientists have contributed to the design and calculation of CLT panels: H.J. Blass [14], K. Hofstetter [15], G. Schickhofer [16], Reinhard B. [17].

The purpose and objectives of the research. The purpose of this work`s research is to present an engineering method for calculating prefabricated cross-laminated timber houses:

1. Improvement of engineering normative methods of cross-laminated timber panels calculation.
2. Numerical modeling of the multi-storey prefabricated cross-laminated timber houses calculation.
3. Development of recommendations for the multi-storey prefabricated cross-laminated timber houses calculation by the finite element method.

Engineering methods improvement of cross-laminated timber panels calculation. After analyzing the currently existing analytical calculation methodology, experimental data and the results of numerical modeling of cross-laminated timber panels by finite elements method [18, 19] the possibility of improving the analytical calculation methodology is substantiated. The essence of improvement lies in the use of the cross section`s given geometric characteristics in analytical formulas. Moreover, the following formulas allow to calculate the panels not only with different thicknesses of layers, but also of different classes of timber strength in each layer. In Fig. 1, as an example, a five-layer panel is given.

A reduced cross-sectional area across the x-axis (force axis along the fibers of the boards` outer layers) for a cross-laminated timber panel is generally determined by the formula:

$$A_{x,ef} = \sum A_{x,i} \frac{E_{x,i}}{E_x}, \qquad (1)$$

where: $A_{x,i}$ – the area of the i-th layer`s boards cross section (cross section perpendicular to the x-axis – along the fibers of timber boards of the outer layer); E_x – an elasticity module of the boards relative to the x-axis, along the fibers of the outer layer; $E_{x,i}$ – an elasticity module of the i-th layer of boards relative to the x-axis, which coincides with the direction of the fibers of the outer layer.

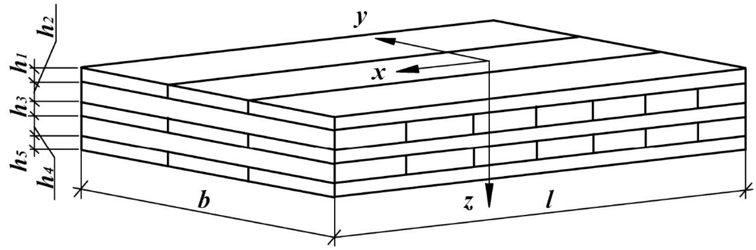

Fig. 1. Geometric parameters of a five-layer cross-laminated timber panel

The reduced cross-sectional area across the x-axis (the axis of force application along the fibers of the boards` outer layers) for a cross-laminated timber panel made of boards of the same strength class is determined by the formula:

$$A_{x,ef} = \sum A_{x,i} + \sum A_{y,i} \frac{E_y}{E_x}, \tag{2}$$

where: $\Sigma A_{x,i}$ – the total cross-sectional area of all layers of boards whose direction of fibers coincides with the x-axis (the cross-section is perpendicular to the x-axis); $\Sigma A_{y,i}$ – the cross-sectional area of all layers of boards whose direction of fibers coincide with the y-axis (the cross-section is perpendicular to the x-axis); $E_{\mathrm{x}} = E_{0,\mathrm{mean}}$ – the elasticity modulus of boards along the fibers; $E_y = E_{90,\mathrm{mean}}$ – the elasticity modulus of the boards across the fibers.

The reduced cross-sectional area across the y-axis (the axis of force application across the fibers of the boards` outer layers) for the panel of cross-laminated timber in general is determined by the formula:

$$A_{y,ef} = \sum A_{y,i} \frac{E_{y,i}}{E_x}, \tag{3}$$

where: $A_{y,i}$ – the cross-sectional area of the i-th layer of boards (cross section perpendicular to the y-axis – across the timber fibers of the boards of the outer layer); E_x – the elasticity modulus of boards along the fibers; $E_{y,i}$ – the elasticity modulus of the boards` i-th layer relative to the y-axis, perpendicular to the direction of the fibers of the outer layer of the boards.

The reduced cross-sectional area across the axis y (the axis of force application across the fibers of the boards` outer layers) for a panel of cross-laminated timber made of boards of the same strength class is determined by the formula:

$$A_{y,ef} = \sum A_{x,i} \frac{E_y}{E_x} + \sum A_{y,i}, \tag{4}$$

where: $\Sigma A_{x,i}$ – the total cross-sectional area of all layers of boards whose direction of fibers coincides with the x-axis (cross-section perpendicular to the y-axis); $\Sigma A_{y,i}$ – the cross-sectional area of all layers of boards whose direction of fibers coincides with the y-axis (the cross-section is perpendicular to the y-axis); $E_x = E_{0,\text{mean}}$ – the elasticity modulus of boards along the fibers; $E_y = E_{90,\text{mean}}$ – the elasticity modulus of the boards across the fibers.

The reduced resistance moment of the cross section perpendicular to the x-axis should be determined by the formula:

$$W_{x,ef} = \frac{I_{x,ef}}{h_z}, \tag{5}$$

in which: $I_{x,ef}$ – the reduced inertia moment of panel cross section perpendicular to the x-axis, which should be determined by formula (6); h_z – the distance from the gravity center of the cross section to the extreme fiber in which the stress is determined.

The reduced inertia moment of the panel cross section perpendicular to the x-axis in general is determined by the formula:

$$I_{x,ef} = \sum I_{x,i} \frac{E_{x,i}}{E_x} + \sum a_i^2 A_{x,i} \frac{E_{x,i}}{E_x}, \tag{6}$$

where: $I_{x,i}$ – the inertia moment of section perpendicular to the x-axis and the i-th layer of the boards; $A_{x,i}$ – the area of the i-th layers boards cross section perpendicular to the x-axis; a_i – the distance from the neutral axis of the panel section to the axis of the section center of the boards` i-th layer; E_x – the elasticity modulus of boards along the fibers; $E_{x,i}$ – the elasticity modulus of the boards i-th layer relative to the x-axis.

The reduced inertia moment of the cross section perpendicular to the x-axis for a cross-laminated timber panel made of boards of the same strength class is determined by the formula:

$$I_{x,ef} = \sum I_{x,i,0} + \sum I_{x,i,90} \frac{E_y}{E_x} + \sum a_i^2 A_{x,i,0} + \sum a_i^2 A_{x,i,90} \frac{E_y}{E_x}, \tag{7}$$

where: $I_{x,i,0}$, $I_{x,i,90}$ – the inertia moments of the cross section perpendicular to the x-axis of the i-th layer boards whose fibers coincide with the x-axis and are perpendicular to the x-axis, respectively; $A_{x,i,0}$, $A_{x,i,90}$ – the areas of the perpendicular to the x-axis cross section of the boards i-th layer whose fibers coincide with the x-axis and are perpendicular to the x-axis, respectively; a_i – the distance from the neutral axis of the panel section to the axis of the section center of the boards i-th layer; $E_x = E_{0,\text{mean}}$ – the elasticity modulus of boards along the fibers; $E_y = E_{90,\text{mean}}$ – the elasticity modulus of the boards across the fibers.

The reduced resistance moment of the cross section perpendicular to the y-axis should be determined by the formula:

$$W_{y,ef}=\frac{I_{y,ef}}{h_z}, \tag{8}$$

in which: $I_{y,ef}$ – the reduced inertia moment of panel cross section perpendicular to the y-axis, which should be determined by formula (9); h_z – the distance from the gravity center of the cross section to the extreme fiber in which the stress is determined.

The reduced inertia moment of the panel cross section perpendicular to the y-axis in general is determined by the formula:

$$I_{y,ef}=\sum I_{y,i}\frac{E_{y,i}}{E_x}+\sum a_i^2 A_{y,i}\frac{E_{y,i}}{E_x}, \tag{9}$$

where: $I_{y,i}$ – the inertia moment of section perpendicular to the y-axis and the i-th layer of the boards; $A_{y,i}$ – the area of the i-th layer`s boards cross section perpendicular to the y-axis; $a_i$ – the distance from the neutral axis of the panel section to the axis of the section center of the boards` i-th layer; E_x – the elasticity modulus of boards along the fibers; $E_{y,i}$ – the elasticity modulus of the boards` i-th layer relative to the y-axis.

The reduced inertia moment of the cross section perpendicular to the y-axis for a cross-laminated timber panel made of boards of the same strength class is determined by the formula:

$$I_{y,ef}=\sum I_{y,i,90}\frac{E_y}{E_x}+\sum I_{y,i,0}+\sum a_i^2 A_{y,i,90}\frac{E_y}{E_x}+\sum a_i^2 A_{y,i,0}, \tag{10}$$

where: $I_{y,i,0}$, $I_{y,i,90}$ – the inertia moments of the cross section perpendicular to the y-axis of the i-th layer boards whose fibers coincide with the y-axis and are perpendicular to the y-axis, respectively; $A_{y,i,0}$, $A_{y,i,90}$ – the areas of the perpendicular to the y-axis cross section of the boards` i-th layer whose fibers coincide with the y-axis and are perpendicular to the y-axis, respectively; $a_i$ – the distance from the neutral axis of the panel section to the axis of the section center of the boards` i-th layer; E_x – the elasticity modulus of boards along the fibers; $E_{y,i}$ – the elasticity modulus of the boards` i-th layer relative to the y-axis.

When calculating the panel as a single element and to apply the finite element method (FEM) when calculating both single panels and buildings made of CLT panels as a whole, we compare the reduced stiffness with the stiffness for a monolithic section.

Let us determine the reduced elasticity modulus of the CLT panel along the x-axis (Fig. 1) based on the condition:

$$I_{x,ef}\cdot E_x=I_{x,\mathrm{br}}E_1, \tag{11}$$

where: $I_{x,ef}$ – the reduced inertia moment of panel cross section perpendicular to the x-axis, which should be determined by formula (6); $E_x=E_{0,\mathrm{mean}}$ – the elasticity modulus of boards along the fibers; $I_{x,\mathrm{br}}$ – the inertia moment of conditionally continuous cross section perpendicular to the x-axis for a cross-laminated timber panel; E_1 – the reduced elasticity modulus of the CLT panel along the x-axis, which is determined by formula (12).

$$E_1 = \frac{I_{x,ef} \cdot E_x}{I_{x,\mathrm{br}}} \,. \tag{12}$$

The elasticity modulus of the CLT panel along the y-axis is based on the condition:

$$I_{y,ef} \cdot E_y = I_{y,\mathrm{br}} E_2 \,, \tag{13}$$

where: $I_{y,ef}$ – the reduced inertia moment of panel cross section perpendicular to the y-axis, which should be determined by formula (9); $E_y = E_{90,\mathrm{mean}}$ – the elasticity modulus of the boards across the fibers; $I_{y,\mathrm{br}}$ – the inertia moment of conditionally continuous cross section perpendicular to the y-axis for a cross-laminated timber panel; E_2 – the reduced elasticity modulus of the CLT panel along the y-axis, which is determined by formula (14).

$$E_2 = \frac{I_{y,ef} \cdot E_y}{I_{y,\mathrm{br}}} \,. \tag{14}$$

Numerical researches of the cross-laminated timber panels` stress-strain state in the modeling of three-dimensional and flat finite elements with reduced stiffness characteristics. To substantiate the possibility of calculating CLT panels by the finite element method (FEM) in modern software packages (SP) conducted numerous studies. Numerical researches of CLT panels were performed using three-dimensional finite elements (FE) №36 and flat FE №.№41, giving them the panel reduced rigidity characteristics according to the formulas given above using the software package Lira SAPR, whose capabilities are described in detail in [20, 21].

The studies concerned 3, 5 and 7-layer panels, spans of 3, 6 and 9 m, with a load of 1.5 kN/m^2 and 5.0 kN/m^2 evenly distributed over the area. All layers of the CLT panel are made of wood of strength class C24, with the following material characteristics: $E_{0,\mathrm{mean}}$=11000 MPa, $E_{90,\mathrm{mean}}$=370 MPa, G_{mean}=690 MPa.

Volumetric FE №36 were modeled with the provision of physical and mechanical characteristics of wood: elasticity modulus of wood along the fibers $E_1 = E_{0,\mathrm{mean}}$=11000 MPa, elasticity modulus of wood across the fibers $E_2 = E_3 = E_{90,\mathrm{mean}}$=370 MPa, shear modulus $G = G_{\mathrm{mean}}$= 690 MPa. The accepted size of the finite element is 0.01×0.01×0.01 m.

Flat FE №41 were modeled by giving them physical and mechanical characteristics of wood: elasticity modulus is determined by the formulas given in the previous paragraph along the fibers E_1 and across the fibers E_2, shear modulus $G = G_{\mathrm{mean}}$ = 690 MPa. The accepted size of the finite element is 0.02×0.02 m.

The elasticity modules for CLT panels are: for the three-layer panel E_1=10606 MPa, E_2=764 MPa; for the five-layer panel E_1=8789 MPa, E_2=2581 MPa; for the seven-layer panel E_1=7932 MPa, E_2=3438 MPa.

It should be noted that the Poisson's ratios were adopted with the obligatory observance of the condition that the wood has an elastic potential.

The supports of the simulated panels are defined as hinged fixed and hinged movable support.

The results of the research. The results of calculations are presented in a tabular form (Tab. 1, 2, 3, 4, 5, 6) and figures (Fig. 2, 3, 4).

For short spans, up to 3 meters, the difference in the calculation methods for determining the deflections for three- and five-layer panels at different load intensities is within 5%, and between FEM volumetric and flat FE – 2%. The difference in the determination of stresses by theoretical methods and methods using flat FE is virtually absent. The obtained stress values when using volumetric FEs are almost 17% lower, which can be explained by the discreteness of the given FEs. For seven-layer panels, the difference in the values of deflections between the theoretical method and the FEM increases to 7%, but the difference in stresses drops to 8%. Moreover, the technique with flat FEs actually coincides with the theoretical in determining the stresses.

Table 1

Values of deflections and maximum normal stresses for three-layer CLT panels at evenly distributed load of 1.5 kN/m^2

Span, m		3		6		9	
	$EI_{ef}\,(W_x)$	w	$\sigma_{m,d}$ (M_x)	w	$\sigma_{m,d}$ (M_x)	w	$\sigma_{m,d}$ (M_x)
Measurement units	kNcm^2 (cm^3)	mm	kN/cm^2 (kNcm)	mm	kN/cm^2 (kNcm)	mm	kN/cm^2 (kNcm)
Kreisinger's theory	1,91×10^6	9,72	0,333	152,4	1,332	768,5	2,997
FEM в №36 SP Lira SAPR		9,51	0,277	150,0	1,100	757	2,48
FEM в №41 SP Lira SAPR	1,909×10^6 (578,53)	9,67	0,337 (1,95)	152,0	1,334 (7,72)	767	2,99 (17,3)

Table 2

Values of deflections and maximum normal stresses for three-layer CLT panels at evenly distributed load of 5.0 kN/m^2

Span, m		3		6		9	
	EI_{ef} (W_x)	w	$\sigma_{m,d}$ (M_x)	w	$\sigma_{m,d}$ (M_x)	w	$\sigma_{m,d}$ (M_x)
Measurement units	kNcm^2 (cm^3)	mm	kN/cm^2 (kNcm)	mm	kN/cm^2 (kNcm)	mm	kN/cm^2 (kNcm)
Kreisinger's theory	1,91×10^6	29,605	1,014	464,3	4,058	2341	9,13
FEM в №36 SP Lira SAPR		29,0	0,847	458	3,36	2310	7,55
FEM в №41 SP Lira SAPR	1,909×10^6 (578,53)	29,5	1,030 (5,96)	464	4,079 (23,6)	2340	9,14 (52,9)

Table 3

Values of deflections and maximum normal stresses for five-layer CLT panels at evenly distributed load of 1.5 kN/m^2

Span, m		3		6		9	
	EI_{ef} (W_x)	w	$\sigma_{m,d}$ (M_x)	w	$\sigma_{m,d}$ (M_x)	w	$\sigma_{m,d}$ (M_x)
Measurement units	kNcm^2 (cm^3)	mm	kN/cm^2 (kNcm)	mm	kN/cm^2 (kNcm)	mm	kN/cm^2 (kNcm)
Kreisinger's theory	7,26×10^6	2,83	0,158	43,56	0,63	219	1,42
FEM в №36 SP Lira SAPR		2,68	0,140	42,300	0,560	214	1,26
FEM в №41 SP Lira SAPR	7,32×10^6 (1331,66)	2,74	0,158 (2,1)	43,2	0,626 (8,33)	218	1,40 (18,7)

Table 4

Values of deflections and maximum normal stresses for five-layer CLT panels at evenly distributed load of 5.0 kN/m^2

Span, m		3		6		9	
	EI_{ef} (W_x)	w	$\sigma_{m,d}$ (M_x)	w	$\sigma_{m,d}$ (M_x)	w	$\sigma_{m,d}$ (M_x)
Measurement units	kNcm^2 (cm^3)	mm	kN/cm^2 (kNcm)	mm	kN/cm^2 (kNcm)	mm	kN/cm^2 (kNcm)
Kreisinger's theory	7,26×10^6	8,176	0,456	125,97	1,824	633	4,1
FEM в №36 SP Lira SAPR		7,78	0,407	123,0	1,620	619	3,65
FEM в №41 SP Lira SAPR	7,32×10^6 (1331,66)	7,94	0,457 (6,09)	125,0	1,810 (24,1)	632	4,07 (54,2)

Table 5

Values of deflections and maximum normal stresses for seven-layer CLT panels at evenly distributed load of 1.5 kN/m^2

Span, м		3		6		9	
	EI_{ef} (W_x)	w	$\sigma_{m,d}$ (M_x)	w	$\sigma_{m,d}$ (M_x)	w	$\sigma_{m,d}$ (M_x)
Measurement units	kNcm^2 (cm^3)	mm	kN/cm^2 (kNcm)	mm	kN/cm^2 (kNcm)	mm	kN/cm^2 (kNcm)
Kreisinger's theory	1,79×10^7	1,27	0,0963	19,168	0,385	95,81	0,867
FEM в №36 SP Lira SAPR		1,18	0,088	18,4	0,351	92,9	0,79
FEM в №41 SP Lira SAPR	1,81×10^7 (2355,52)	1,20	0,096 (2,26)	18,9	0,380 (8,95)	95,3	0,853 (20,1)

Table 6

Values of deflections and maximum normal stresses for seven-layer CLT panels at evenly distributed load of 5.0 kN/m^2

Span, м		3		6		9	
	EI_{ef} (W_x)	w	$\sigma_{m,d}$ (M_x)	w	$\sigma_{m,d}$ (M_x)	w	$\sigma_{m,d}$ (M_x)
Measurement units	kNcm^2 (cm^3)	mm	kN/cm^2 (kNcm)	mm	kN/cm^2 (kNcm)	mm	kN/cm^2 (kNcm)
Kreisinger's theory	1,79×10^7	3,51	0,266	52,88	1,063	264,6	2,39
FEM в №36 SP Lira SAPR		3,26	0,244	51,0	0,973	257	2,19
FEM в №41 SP Lira SAPR	1,81×10^7 (2355,52)	3,31	0,265 (6,25)	52,2	1,053 (24,8)	264	2,36 (55,6)

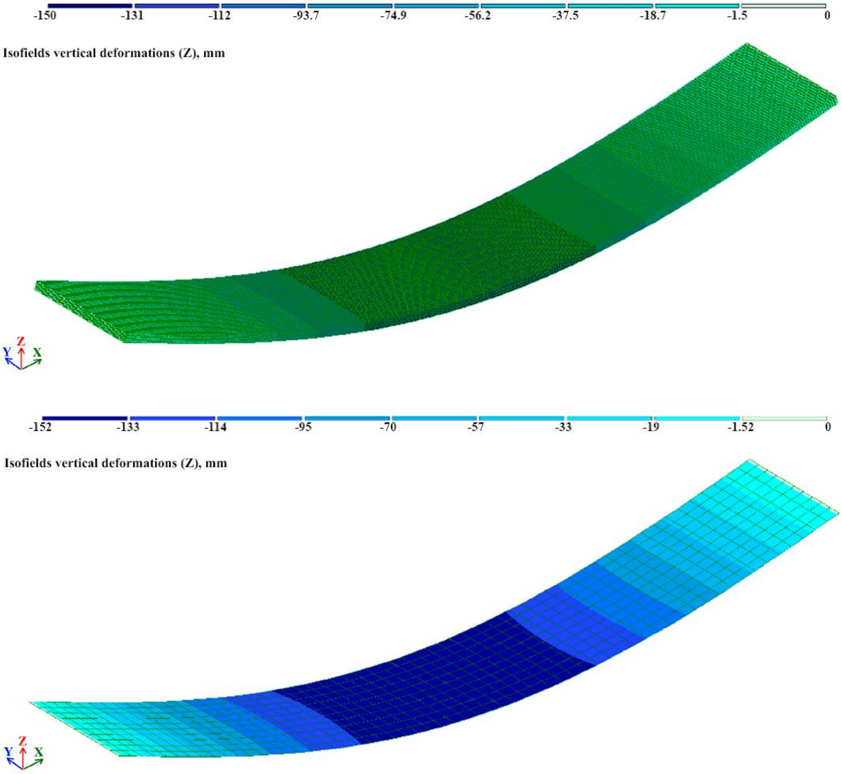

Fig. 2. Isofields of three-layer CLT panels` vertical deformations, span of 6 m, at evenly distributed load of 1.5 kN/m^2, at modeling by volume (top) and flat (bottom) finite elements

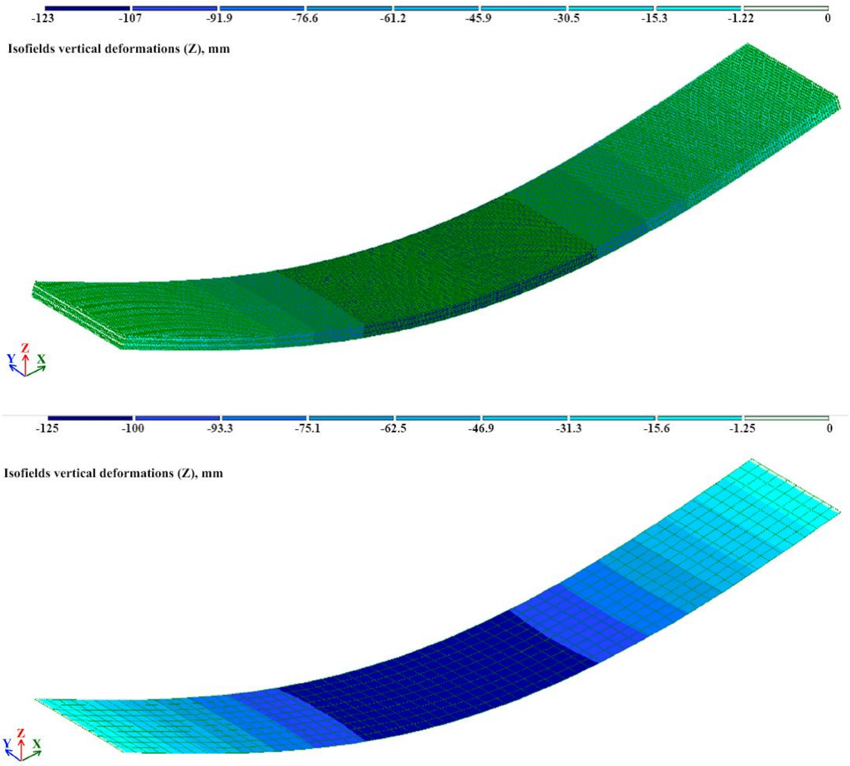

Fig. 3. Isopolies of five-layer CLT panels` vertical deformation, span of 6 m, at evenly distributed loading of 1,5 kN/m^2, at modeling by volume (top) and flat (bottom) finite elements

For spans of 6 meters, the difference in the calculation methods for determining the deflections for all types of panels at different load intensities is within 4%, and between the FEM volumetric and flat FE – 2.7%. The difference in determining the stresses by the theoretical method and the method using flat FE does not exceed 1.5%. The obtained values of stresses when using volumetric FE, for three-layer panels, are almost 17.5% lower. For five- and seven-layer panels, the difference in normal stresses values between the theoretical method and the FEM increases to 8.8 and 11%, respectively.

For panels with spans of 9 meters, the difference in the calculation methods for determining the deflections for all types of panels at different load intensities is within 3%, and between FEM volumetric and flat FE – 2.5%. The difference in the determination of stresses by theoretical methods and methods using flat FEs almost coincides. The obtained values of stresses during application showed the same difference as for panels with spans of 6 m.

Based on the data obtained in tables 1, 2, 3, 4, 5, 6, and described above, we can conclude that the use of flat FE №41 using the above physical and mechanical characteristics gives a fairly high convergence of results with

Kreisinger's theory, which confirms the possibility of its application in the modeling of both individual cross-laminated timber panels and houses made of such panels. This modeling can greatly simplify the creation of calculation schemes.

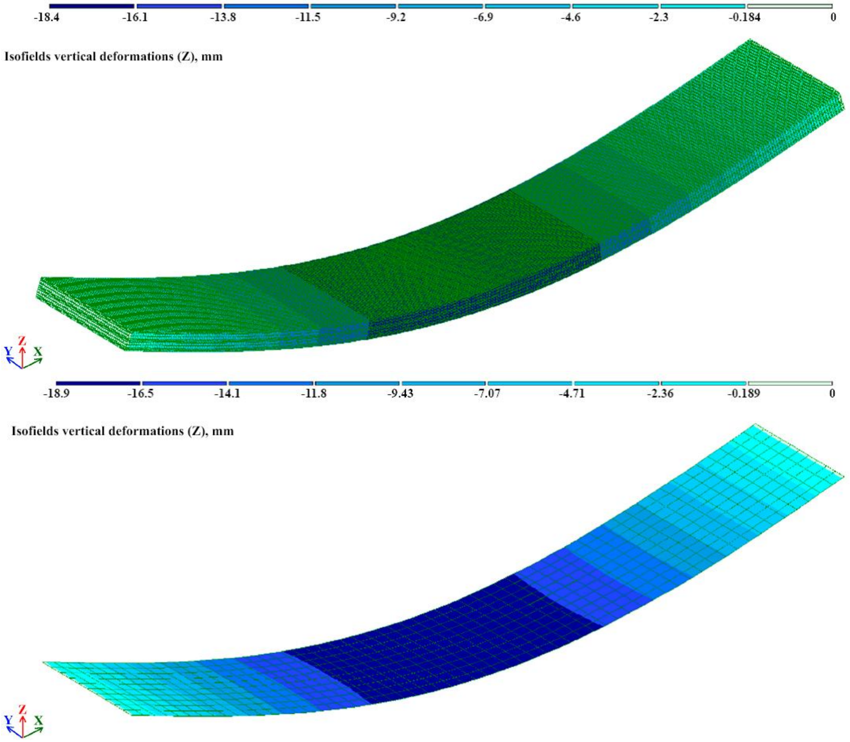

Fig. 4. Isofields of seven-layer CLT panels vertical deformation, span of 6 m, at evenly distributed load of 1.5 kN/m^2, at modeling by volume (top) and flat (bottom) finite elements

Conclusions. 1. The high reliability of the CLT panels calculation results using the existing analytical method, FEM using volumetric FE №36 and flat FE №41 using the reduced elasticity modulus according to the above method, adjusting the Poisson's ratios so as to maintain the condition of existence in timber of elastic potential was proved. 2. It is possible to apply FEM with panels modeling by orthotropic panel FE №41 for CLT panels calculation using the reduced modules of elasticity by the technique offered above, by adjustment of the Poisson's coefficients so that the condition of existence in timber of elastic potential remained.

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МЕТОДИКА РОЗРАХУНКУ ПАНЕЛЬНИХ БУДИНКІВ З ПОПЕРЕЧНО-КЛЕЄНОЇ ДЕРЕВИНИ

Актуальність. Будівельні конструкції з поперечно-клеєної деревини набувають все більшого розповсюдження. Досвід проектування та експлуатації дерев'яних конструкцій різноманітного призначення підтверджує доцільність їх використання. Особливого поширення, останнім часом, набуло зведення панельних будинків, в тому числі і багатоповерхових, з поперечно-клеєної деревини. Панелі з поперечно-клеєної деревини використовують в якості несучих стін та плит перекриття і покриття в мало- та багатоповерхових будинках різноманітного призначення. **Мета роботи.** В цій статті запропоноване вирішення задачі розрахунку панелей з поперечно-клеєної деревини за допомогою методу скінчених елементів із застосуванням приведених механічних характеристик матеріалу. Удосконалити інженерну нормативну методику розрахунку панелей з поперечно-клеєної деревини. Наведено уточнені формули по визначенню приведених геометричних та механічних характеристик різних типів панелей з поперечно-клеєної деревини, в тому числі, з комбінованої поперечно-клеєної деревини. Наведено алгоритм розрахунку панелей з поперечно-клеєної деревини за допомогою методу скінчених елементів. Наведені результати чисельних досліджень підтверджують достовірність результатів розрахунку панелей з ПКД з застосуванням існуючої аналітичної методики, МСЕ з застосуванням об'ємних СЕ №36 та плоских СЕ №41 з використанням приведених модулів пружності за запропонованою вище методикою. **Результати.** Обґрунтовано можливість застосування плоских скінчених елементів з врахуванням ортотропних властивостей для розрахунку панелей з поперечно-клеєної деревини за умови використання приведених модулів пружності за запропонованою вище методикою, коригуванням коефіцієнтів Пуассона таким чином щоб зберігалась умова існування в деревини пружного потенціалу.

Ключові слова: поперечно-клеєна деревина, панельний будинок, розрахункова схема, метод скінчених елементів, напружено-деформований стан, система ґрунтова основа-фундамент-надземна конструкція.

Михайловский Д.В.

МЕТОДИКА РАСЧЕТА ПАНЕЛЬНЫХ ДОМОВ ИЗ ПОПЕРЕЧНО-КЛЕЕНОЙ ДРЕВЕСИНЫ

Актуальность. Строительные конструкции из поперечно-клееной древесины приобретают все большее распространение. Опыт проектирования и эксплуатации деревянных конструкций различного назначения подтверждает целесообразность их использования. Особое внимание, в последнее время, приобрело возведение панельных домов, в том числе и многоэтажных, с поперечно-клееной древесины. Панели из поперечно-клееной древесины используют в качестве несущих стен и плит перекрытия и покрытия в мало- и многоэтажных домах различного назначения. **Цель работы.** В этой статье предложено решение задачи расчета панелей из поперечно-клееной древесины с помощью метода конечных элементов с применением приведенных механических характеристик материала. Усовершенствовать инженерную нормативную методику расчета панелей из поперечно-клееной древесины. Приведены уточненные формулы по определению приведенных геометрических и механических характеристик различных типов панелей с поперечно-клееной древесины, в том числе, с комбинированной поперечно-клееной древесины. Приведен алгоритм расчета панелей из поперечно-клееной древесины с помощью метода конечных элементов. Приведенные результаты многочисленных исследований подтверждают достоверность результатов расчета панелей с ПСД с применением существующей аналитической методики, МСЭ с применением объемных СЭ №36 и плоских СЭ №41 с использованием приведенных модулей упругости по предложенной выше методике. **Результаты.** Обоснована возможность применения плоских конечных элементов с учетом ортотропных свойств для расчета панелей из поперечно-клееной древесины при использовании приведенных модулей упругости по предложенной выше методике, корректировкой коэффициентов Пуассона таким образом, чтобы сохранялась условие существования в древесины упругого потенциала.

Ключевые слова: поперечно-клееная древесина, панельный дом, расчетная схема, метод конечных элементов, напряженно-деформированное состояние, система грунтовая основа-фундамент-надземная конструкция.

УДК 624.011
Михайловський Д.В. **Методика розрахунку панельних будинків з поперечно-клеєної деревини** / Опір матеріалів і теорія споруд: наук.-тех. збірн. – К.: КНУБА, 2021. – Вип. 107. – С. 75-88. – Англ.

Наведено інженерну методику розрахунку панелей з поперечно-клеєної деревини за допомогою плоских скінчених елементів з врахуванням ортотропних властивостей за умови використання приведених модулів пружності з коригуванням коефіцієнтів Пуассона таким чином щоб зберігалась умова існування в деревини пружного потенціалу.

Табл. 6. Іл. 4. Бібліогр. 21 назв.

УДК 624.011
Mykhailovskyi D.V. **Method of calculation of panel buildings from cross-laminated timber** / Strength of Materials and Theory of Structures: Scientific-and-technical collected articles. – K.: KNUBA, 2021. – Issue 107. – P. 75-88.

The engineering method of calculation of panels from cross-laminated timber by means of flat finite elements taking into account orthotropic properties under the condition of use of the resulted modules of elasticity with adjustment of Poisson's coefficients so that the condition of existence in wood of elastic potential remains.

Tabl. 6. Fig. 4. Ref. 21.

УДК 624.011
Михайловский Д.В. **Методика расчета панельных домов из поперечно-клееной древесины** / Сопротивление материалов и теория сооружений: науч.-тех. сборн. – К.: КНУСА, 2021. – Вип. 107. – С. 75-88. – Англ.

Приведена инженерная методика расчета панелей из поперечно-клееной древесины с помощью плоских конечных элементов с учетом ортотропных свойств при использовании приведенных модулей упругости с корректировкой коэффициентов Пуассона таким образом, чтобы сохранялась условие существования в древесины упругого потенциала.

Табл. 6. Ил. 4. Библиогр. 21 назв.

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