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TEST METHOD OF CLT BY TENSION PERPENDICULAR TO GRAIN

It is known that cross laminated timber (CLT) is a relatively new material in timber design. There is no information about its behavior and strength in tests by tension perpendicular to grain. Little information available is based only on simple tests for assessing the bearing capacity of some variants of devices which are used for the installation of CLT panels. In practice tension perpendicular of CLT panels occurs in curved CLT panels and in some wall-floor connections with screws. First proposed of test setup is based on the parameters related to solid timber and glulam after detailed analysis. The main influence factors on the tensile strength perpendicular to grain were investigated, and the necessary sizes of the CLT specimens were determined considering the features of the material structure. The recommendations derived in this publication can be included in standard EN 16351 or EN 408.

Keywords: *cross laminated timber, tension perpendicular to the grain, proposing of size of test specimens, test arrangement.*

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МЕТОДИКА ВИПРОБУВАНЬ ПОПЕРЕЧНОЇ КЛЕЄНОЇ ДЕРЕВИНИ ПРИ РОЗТЯГУ ПОПЕРЕК ВОЛОКОН

Відомо, що поперечна клеєна деревина (ПКД) є відносно новим матеріалом на основі деревини. На сьогоднішній день відсутня інформація щодо міцності ПКД- панелей при розтягу поперек волокон. Деяка інформація існує та ґрунтується на результатах міцності при простих випробуваннях деяких варіантів монтажних кріплень панелей перекриттів. На практиці розтяг поперек волокон ПКД панелей спостерігається у зігнутих панелях, а також у деяких гвинтових з'єднаннях стінових панелей з панелями перекриттів. Уперше запропоновано новий метод дослідження ПКД, що базується на параметрах, які враховують модель випробувань цільної та клеєної деревини після детального аналізу. Досліджені основні впливові фактори на величину міцності при розтягу поперек волокон, та встановлено необхідні розміри зразків ПКД панелей виходячи з особливостей структури матеріалу. Рекомендації, описані у даній публікації, можуть бути включеними до стандарту EN 16351 або EN 408.

Ключові слова: *поперечна клеєна деревина, розтяг поперек волокон, пропозиція розмірів випробувальних зразків, схема випробування.*

Introduction. Moreover, the German national design code contains recommendations for the reinforcement of certain parts of timber elements which are loaded by tension perpendicular to grain. Before resorting to reinforcement, it should be known the strength of material by stressed conditions which result in certain fracture modes. As it is known, ductile fracture mechanism is a more desirable and safer type of timber elements disruption (failure) than brittle failure. Various tests show that it is brittle failure that occurs most often in timber by tension perpendicular to grain. The transfer from brittle to ductile failure mechanism was achieved by using different type of screws.

According to former standards EN 338:2003 and EN 1194:1999 strength properties of solid timber and glulam are dependent on timber density. According to Russian national rules, strength by tension perpendicular to grain of glulam is also dependent on strength classes (3 classes), but German national rules DIN 1052:2008-12 contain only one value of strength by tension perpendicular for all strength classes. Now EN 1194:1999 has been revoked and all the data of strength properties of GLT are stipulated in EN 14080:2013 [11], where strength values by tension perpendicular are changed and considered to be equal for all strength classes. A similar situation occurs in the new version of EN 338:2009 for solid timber, where strength data by tension perpendicular are also equal.

The orientation of annual rings in cross section of solid timber specimens influences the test data of strength and stiffness by tension perpendicular to grain (Fig. 1).

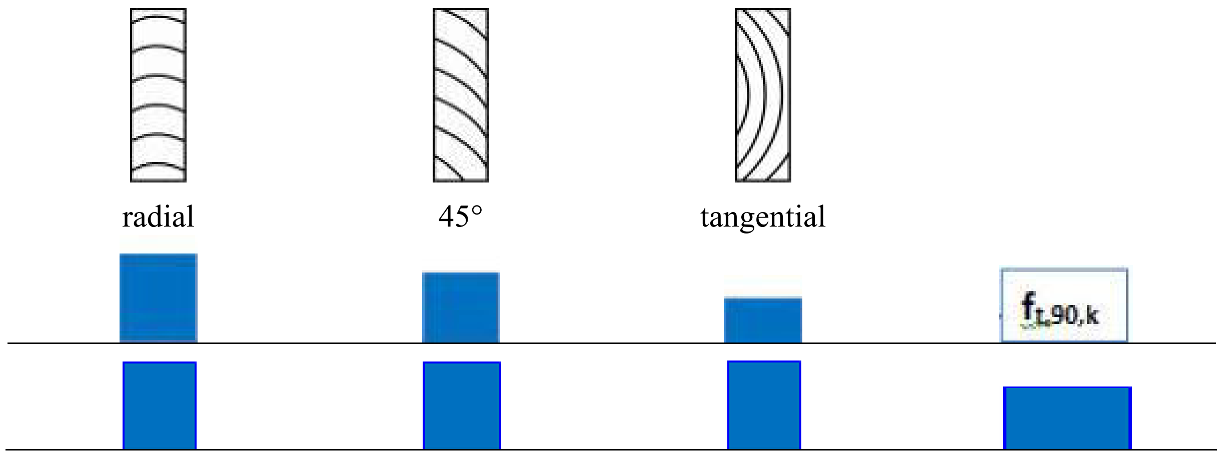

Figure 1 – Dependence of strength and stiffness on the annual ring orientation in specimens of solid timber

The dependence of strength values on size effect in the cross section parameters of solid timber, glulam and LVL occurred by bending and tension along the grain direction. Additionally, GLT shows volume effect by tension perpendicular to grain [3]. In accordance with EN 1193, ST and GLT specimens have geometric parameters as shown in figure 2, which are considered in a number of publications by Blass [1, 2], Aicher [3], Ranta-Maunus [4] and others. The reference volume is accepted as V_0=0,01m^3 and it is taken into account during the design of double tapered, pitched cambered and curved beams where tension stresses perpendicular to the grain appear in the apex zone.

The maximum tensile stress perpendicular to grain by bending of tapered beams should be calculated according to equations which are proposed in EC-5, clause 6.4.3 (8). This clause is a matter of national choice. It is well known that climate change leads to cracks and consequently results in residual working area in longitudinal section.

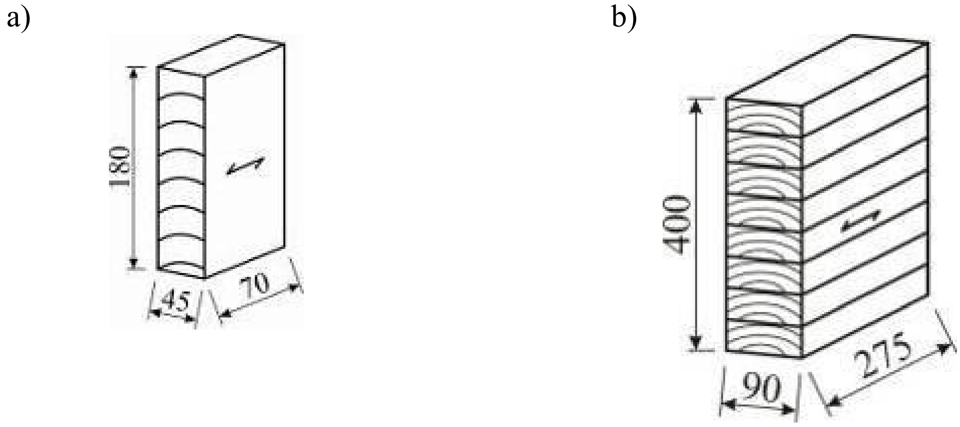

Figure 2 – The size of test specimens according to EN 1193:1998:
a – solid timber; b – glued laminated timber

Cross laminated timber is a new and modern timber plate orientated material in building industry. In practice tension perpendicular of CLT panels occurs in wall-floor connections with screws, as well as in notched connections of floor panels supported on wall panel and in curved CLT panels, as it is shown in figure 3.

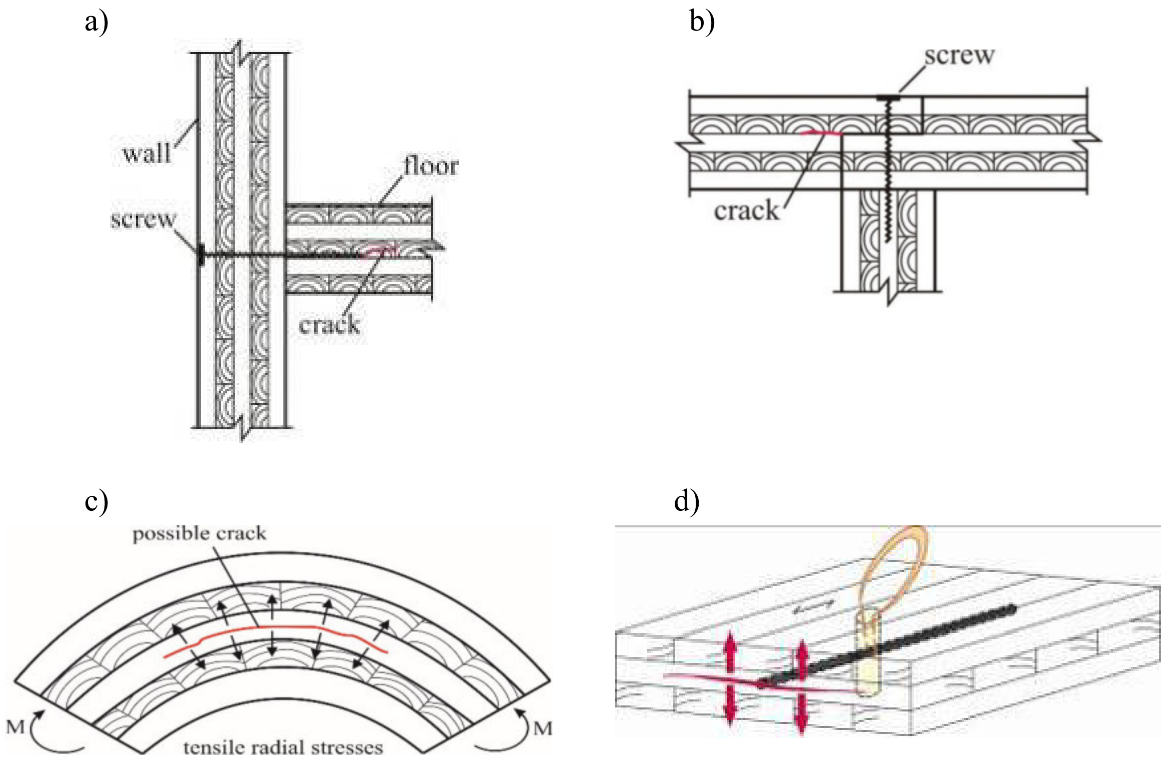

Figure 3 – Examples of tension perpendicular of CLT in practice:
a – wall-floor connection; b – floor-floor -wall connection;
c – curved CLT panels; d – mounting parts

Review of the latest research sources and publications. As it was introduced in section 1, strength by tension perpendicular to grain is dependent on a number of major factors such as density, volume of tested specimens and grain orientation in cross section of solid timber elements (Fig. 4).

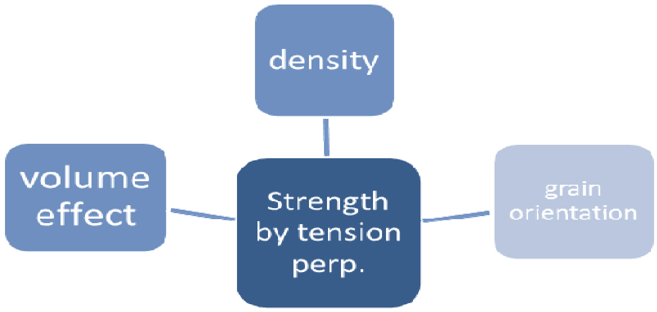

Figure 4 – Main factors that influence the strength by tension perpendicular

The tensile strength for solid timber according to former versions of standards EN 384:1995 [10] and EN 338:2003 was derived on the basis of the relationship between tensile strength perpendicular to grain and density:

EN 384: 1995 $$f_{t,90,k} = 0{,}001 \cdot \rho; \qquad (1)$$

EN 338:2003 $$f_{t,90,k} = \min \begin{cases} 0{,}6 \\ 0{,}0015 \cdot \rho_k . \end{cases} \qquad (2)$$

Strengths properties of glued laminated timber by tension perpendicular to grain according to EN 1194:1999 are based on the following equation:

EN 1194:1999 $$f_{t,90,g,k} = 0{,}2 + 0{,}015 \cdot f_{t,0,1,k}, \qquad (3)$$

where $f_{t,90,g,k}$ is glulam strength perpendicular to grain and $f_{t,0,1,k}$ is the tensile strength parallel to grain of these planks.

The characteristic value of strength $f_{t,90,g,k}$ is related to the reference volume of V_0=0,01m^3. The test method for determining the tensile strength perpendicular to grain of glulam using this reference volume V_0 is stipulated in EN 1193 where the specimen parameters are 90 mm×275 mm×400 mm (Fig. 2) and the volume is 0,0099 m^3.

In order to show more vividly the correlation between density and strength by tension perpendicular in solid wood and glulam, «X» parameter is introduced. Equation (1) and (2) can be written in the following modified way:

$$f_{t,90,k} = \frac{1}{X} \cdot \rho_k \quad \text{or} \quad f_{t,90,k} = \frac{\rho_k}{X}, \qquad (4)$$

which means that X parameter equals:

$$X = \frac{\rho_k}{f_{t,90,k}}. \qquad (5)$$

Tables 1 and 2 show the values of X parameter for solid timber and glulam referring to data taken from EN 338 and EN 1194. The graphic illustration of X parameter is shown in figures 5 and 6.

Table 1 – X parameter for glued laminated timber

	GL24c	GL24h GL28c	GL28h GL32c	GL32h GL36c	GL36h
$f_{t,90,k}$	0,35	0,4	0,45	0,5	0,6
ρ_k	350	380	410	430	450
x	1000	950	911,1	860	750

Table 2 – *X* parameter for solid timber

	C14	C16	C18	C20	C22	C24	C27	C30	C35	C40	C45	C50
$f_{t,90,k}$	0,4	0,5					0,6					
ρ_k	290	310	320	330	340	350	370	380	400	420	440	460
x	**725**	**620**	**640**	**660**	**680**	**700**	**617**	**633**	**667**	**700**	**733**	**767**

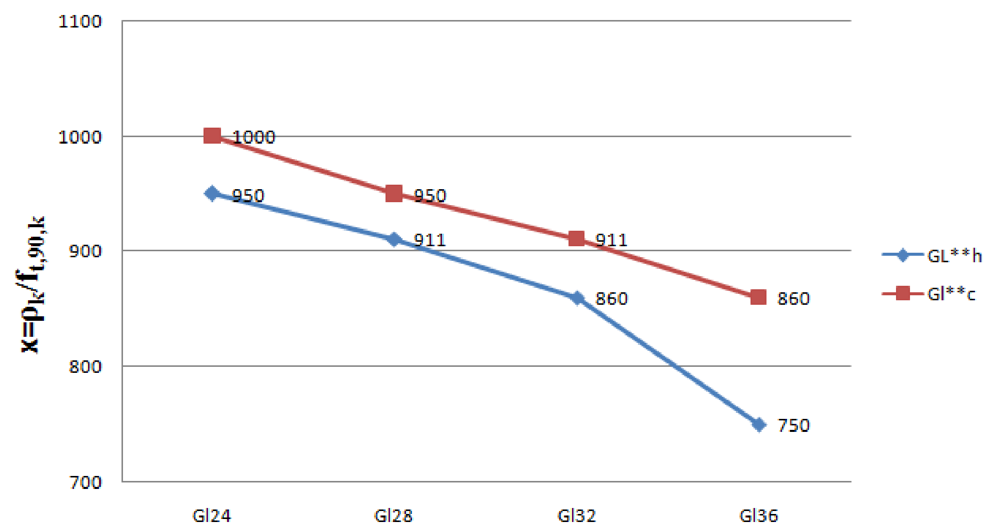

Figure 5 – The illustration of *X* parameter for glued laminated timber

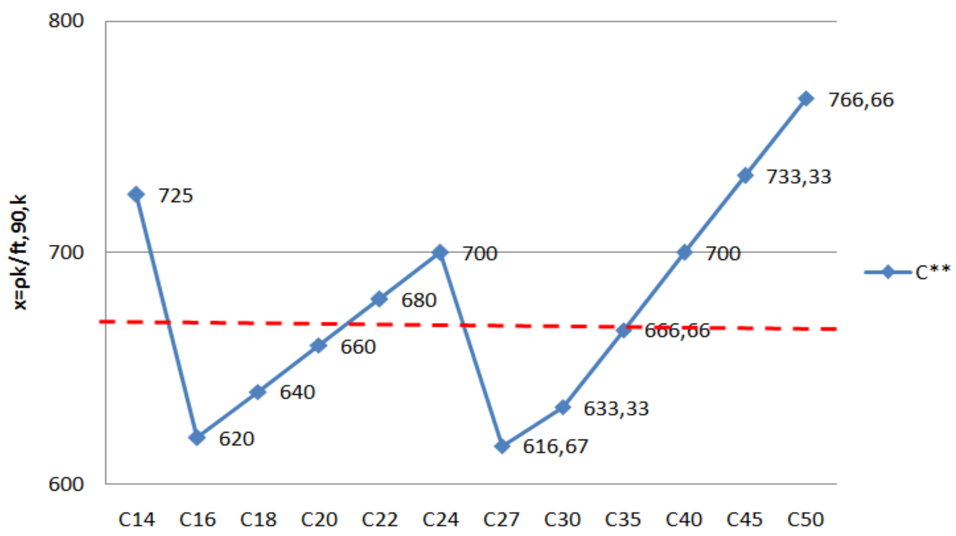

Figure 6 – The illustration of *X* parameter for solid timber

After some transformations, the equation (2) for *X* parameter is expressed in the following form as shown in equation (6):

$$f_{t,90,k} = \min\begin{cases} 0,6 \rightarrow \dfrac{\rho_k}{X} = 0,6 \rightarrow X = \dfrac{\rho_k}{0,6} \\ 0,0015 \cdot \rho_k \rightarrow X = \dfrac{1}{0,0015} = 666,666. \end{cases} \quad (6)$$

For maximum and minimum values of soft solid timber density, X parameter acquires the following values:

$$X_{\min} = \frac{\rho_{k,\min}}{0,6} = \frac{290}{0,6} = 483,33; \qquad X_{\max} = \frac{\rho_{k,\max}}{0,6} = \frac{460}{0,6} = 766,66. \qquad (7)$$

The critical value of X parameter, when equation (2) is divided into two sub-equations, can be found by simple substitution:

$$\frac{\rho_k}{X} = 0,6 \rightarrow \rho_{k,crit} = 0,6 \cdot X_{crit} = 0,6 \cdot 666,667 \cong 400 \text{ kg/m}^3$$

The analysis of the relationship between strength perpendicular and density is important to understand the underpinnings behind the equations and data in the revoked standards or former versions of these standards. Nowadays, there is a certain simplification and averaging in some of the strength and elastic characteristics of glulam and solid timber.

Problem statement. The method of conducting tests into tension perpendicular of ST or GLT is described in EN 1193, as it is shown in figure 7. Now Standard EN 1193:1998 has been revoked and new recommendations are provided in EN 408:2010 [12] with some amendments. Intermediate solid timber or glulam stressed parallel to grain are bonded to the specimens. It is reasonable to install two inductive measuring gauges in diagonal position.

As it is shown in figure 7, in the new version of standard EN 408:2010 it is possible to connect a steel plate immediate to the investigated test specimen or the apply tensioned loading directly to the intermediate wood elements.

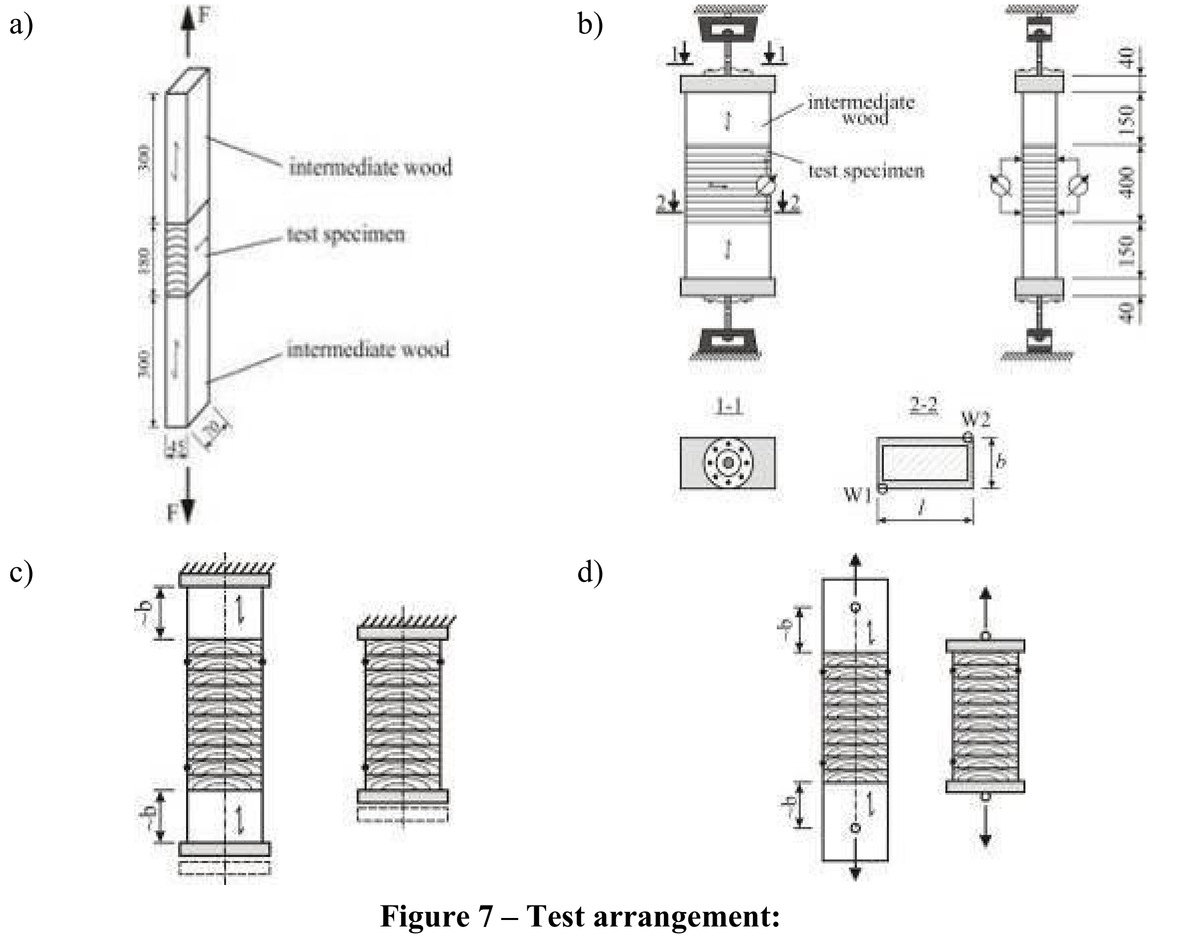

Figure 7 – Test arrangement:
a – solid timber; b – glued laminated timber EN 1193;
c – glued laminated timber EN408:2010

There are data from national standards of different countries and from different periods shown in table 3 that allow a comparison between strength values of solid timber and glulam by tension perpendicular to grain. The strength of glulam is a little higher than that of solid timber and this fact explains the system effect of glued lamellas. CLT is composed of an uneven number of layers which are arranged crosswise to each other at the angle of 90° and the system effect will occur in a different way, influencing the value of strength by tension perpendicular.

Table 3 – Characteristic and design values of strength properties of solid timber (ST) and glued laminated timber (GLT) by tension perpendicular to grain according to standards of different countries

Country	Standard	ST (N/mm²)		GLT (N/mm²)		Equation
		$f_{t,90,k}$	$f_{t,90,d}$	$f_{t,90,k}$	$f_{t,90,d}$	
Euro standard	EN 338	0,4 0,6				softwood hardwood
	EN 384	0,4-0,6				
	EN 1194 (revoke)			0,35-0,6		
	EN 14080:2013	0,5		0,5		for all classes
Germany	DIN 1052:2008-12	0,4		0,5		for all classes
UK	BS 5268-2-2002	0,2-0,47		-	-	$f_{t,90}$=fv/3
USSR	СНиПII-25-80	-		0,6-0,8	0,25-0,35	
Ukraine	ДБН В.2.6-161:2017	0,4* 0,5**		0,5		*softwood **hardwood
Russia	СП 64.13330.2016	0,4-0,6		0,25-0,35	0,12-0,23	
Belarus	ТКП EN 1995-1-1-2009	0,4-0,6		0,35-0,6		
Swiss	SIA 265:2012		0,1		0,15	for all classes

While considering CLT panels with timber based plate material (LVL and plywood) located inside, we need to take into account the strength by tension perpendicular to grain of these materials. If the strength of timber-based materials proves to be lower than the strength of solid timber lamellas, there occurs a system with a weak link.

As it is known, the strengths of plywood and LVL in tension perpendicular to plate area are absent in technical specifications of different producers and technical reports of research organizations, see table 4. That is why the assessment of strength properties of non-homogeneous CLT plates becomes rather difficult.

Table 4 – Characteristic values of strength properties of LVL by tension perpendicular to grain

	Timber based plate material	$f_{t,90,k}$ (N/mm^2)	Organization, № of technical report or certificate	Refe-ren-ces
LVL	Steico Ultralam, 2015	-	DIBT Z-9.1-811	[7]
	Ultralam (Russia), 2010	-	TSNIISK (Moscow) CTO 36554501-021-2010	[9]
	Ultralam (Russia), 2009 2009	- -	MPA Stuttgart Certificate CE 0672-CPD-I 14.04.1 Bericht 51220-901.6453.000/2	[8]
	Kerto –S and –Q Metsa: Wood (Finland) 2004, Update 2016.	-	VTT Certificate № 184/03	[6]
	Kerto – S and -Q Metsa: Wood (Finland)2011	-	VTT Statement VTT-S-05156-11	[5]

The basic material and results. EN 16351 [13] proposed tests for CLT plates with the cross section of lamellas 30×150 mm. Besides, it is known that the technology of CLT production allows some gaps between lamellas in the layers. In addition, lamellas of middle layers in some cases have relieves (see figure 8, right). Gaps and relieves reduce longitudinal section. This weakening needs to be taken into account when calculating strength values.

Figure 8 – Gaps and relives in CLT cross section

Different strength of planks depending on the grain orientation leads to uneven distribution of stresses in the layers of CLT plate. Gaps and relieves create constructive heterogeneity which also influences the uniformity of stress distribution (see figure 9).

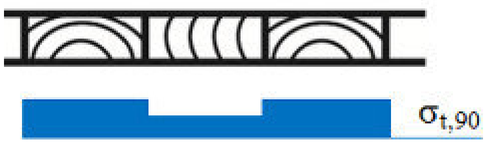

Figure 9 – Uneven distribution of stresses by tension perpendicular to grain

As it is shown in figure 7, the investigated test specimens are glued to both sides of the timber element and then glued to steel plates. Grain direction in auxiliary timber elements coincides with the direction of the applied load. The steel plate can be 40 mm thick, as in the test for GLT in accordance with EN 1193:1998.

Test setup can be arranged in two ways with difference volume. The first version is simple and can be used to obtain the difference and calculate the volume factor in CLT. In this proposed arrangement the tensioned perpendicular area of timber specimens is different and the system effect will influence the obtained test data. The volume of specimen in figure 10 (on the right) is 0,00945m^3 which is close to the reference volume of glulam

(0,01m³). The area of cross section exceeds 2500 mm² as it is recommended by standard EN 408:2013 for GLT. The increased area of tested specimen is explained by the fact that CLT is a plate timber material. The width of the specimen is similar to GLT (more than 100mm) and it is proposed to use 150mm as a reference size of planks.

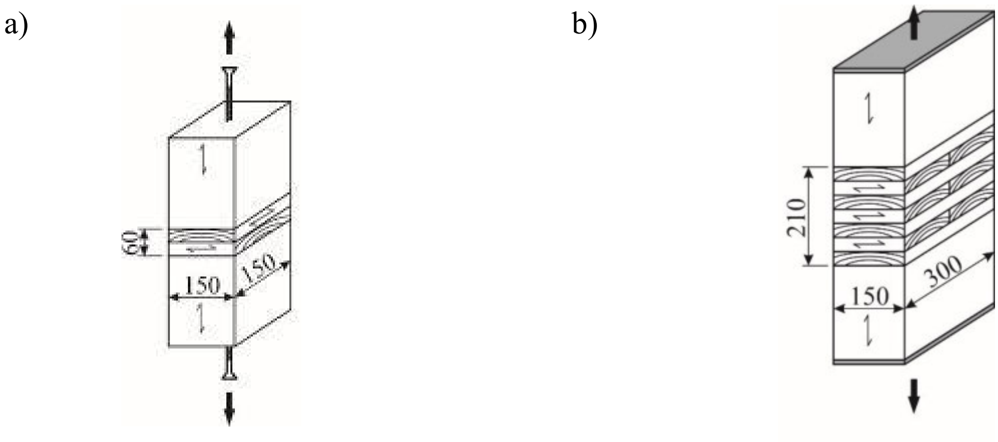

Figure 10 – Test arrangement for CLT:
a – small specimen; b – CLT specimen

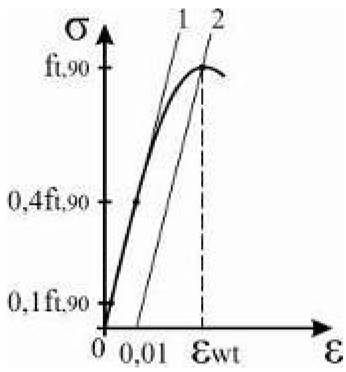

Figure 11 – Proposal for the loading protocol

The load F shall be applied at the constant rate of cross head movement throughout the test. The rate of loading shall be adjusted so that the maximum load $F_{t,90,max}$ is reached within (300 ± 120) s.

The structure of CLT panels assumes the use LVL and plywood in the middle layers. However, the values of strength of timber-based materials by tension perpendicular to grain are unknown and this fact makes it more difficult to analyze and predict the strength this type of CLT panels. Table 4 shows that research laboratories have not yet considered the strength by tension perpendicular to grain in flatwise position of timber based materials such as LVL and plywood. EN 16351 [13] does not contain exact information as to how many layers of LVL or plywood a CLT panel can possibly have (see figure 12). Nor does it say anything about the acceptable percentage of these layers in timber-based plate materials.

Figure 12 – Variants of CLT panels with LVL or plywood

Basic principles of arranging tests into tension perpendicular to grain for CLT have been transferred from the methods proposed for ST and GLT. The suggested proposal for a similar test into CLT panels takes into account the fact that CLT is a plate building material and the plate configuration of specimens is preferable.

The issues of size effect (area factor) and volume effect remain open and require further investigation effort. The reference volume V_0=0,01 for CLT is obviously small in comparison with the volume of CLT panel. Without experimental results it is not possible to determine what type of law of distribution corresponds to CLT by tension perpendicular to grain.

The strength of CLT panels with LVL and plywood in the middle layers is difficult to assess by tension perpendicular to grain because the strength of these veneer-based materials is unknown in this type of stress condition.

The knowledge of strength by tension perpendicular allows us to take decisions which will decrease action perpendicular or suggest reinforcement of basic connections, such as wall-floor connection (see figure 13).

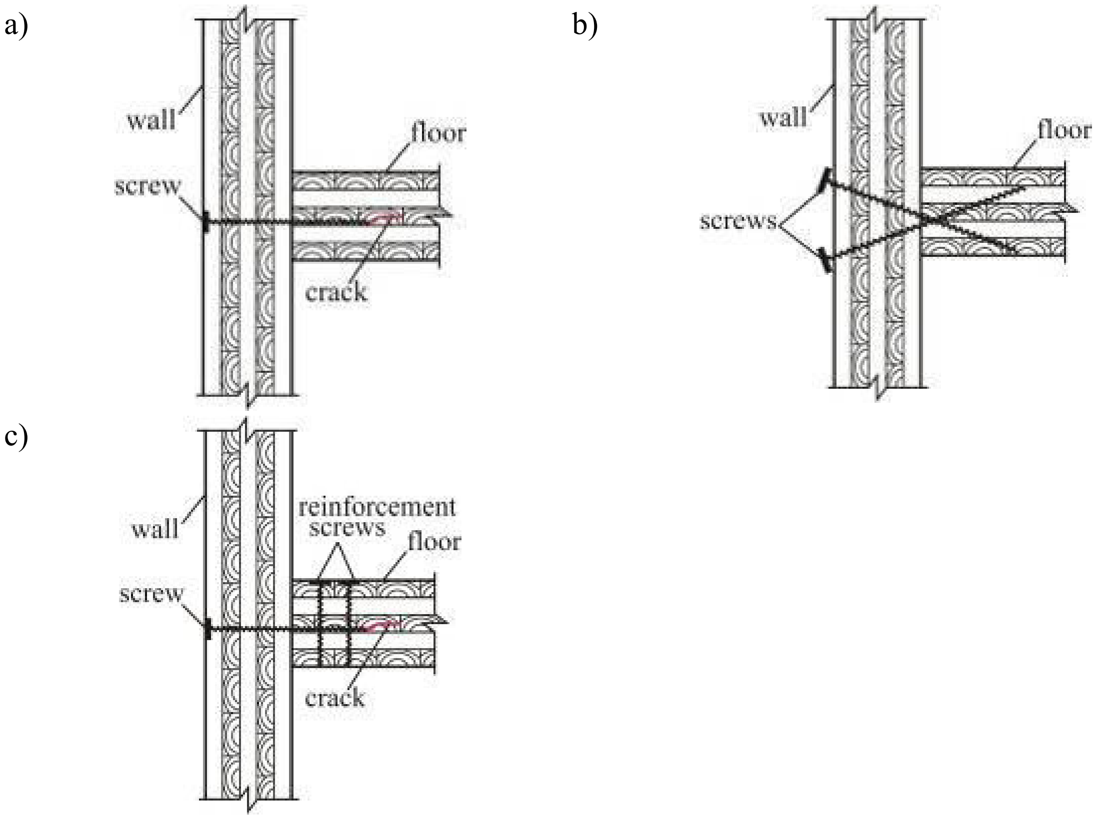

Figure 13 – Variants of connection modification:
a – basic connection; b – decrease action perpendicular; c – reinforced basic connection

The reduction of action perpendicular is achieved by installing screws at angles different from the layers direction in CLT floor element. The inclination of the screws can occur in two planes.

Conclusions. The resulting proposal for test setup is based on the parameters related to solid timber and glulam, also taking into account the test model for CLT. The recommendations derived in this publication can be included in standard EN 16351 or EN 408. In addition, there is a plan to conduct a comprehensive test considering the above-described investigation into CLT by tension perpendicular, allowing further discussion on the dependence between strength and the above-mentioned factors.

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