MACHINE BUILDING

МАШИНОБУДУВАННЯ

UDC 620.17 : 624.011.1

S. Shekhorkina, PhD, Assoc. Prof.,
K. Shliakhov, PhD, Assoc. Prof.,
A. Sopilniak, PhD, Assoc. Prof.
State higher educational institution «Prydniprovska State Academy of Civil Engineering and Architecture», 24-A, Chernyshevskoho Str., Dnipro, Ukraine, 49600; e-mail: S_VT@ukr.net

EXPERIMENTAL INVESTIGATION OF LOAD-BEARING CAPACITY AND DEFLECTIONS OF FULL-SCALE GLUED LAMINATED TIMBER BEAMS

С.Є. Шехоркіна., К.В. Шляхов, А.М. Сопільняк. **Експериментальне дослідження несучої здатності та прогинів натурних клеєних дерев'яних балок.** Конструкційна клеєна деревина завдяки високим фізико-механічним якостям (міцність, жорсткість, стабільність розмірів, різноманітність форми поперечного перерізу, придатність до переробки тощо) широко використовується в будівлях і спорудах різного призначеня. В Україні клеєні дерев'яні конструкції добре відомі і застосовуються як у малоповерховому приватному будівництві, так і при зведенні громадських будівель і споруд. З переходом до проектування дерев'яних конструкцій згідно Європейських норм виникають проблеми оцінки несучої здатності клеєних дерев'яних конструкцій, пов'язані з недостатнім обсягом даних за фізико-механічних і деформаційних властивостей клеєного бруса, який виготовляється на території України. Метою роботи було визначення несучої здатності на згин і прогинів натурних клеєних дерев'яних балок під дією зосередженого навантаження в середині прольоту. Для проведення дослідження були використані балки довжиною 9880 мм, виготовлені з використанням пиломатеріалів деревини сосни і однокомпонентного поліуретанового клею. Розміри поперечного перерізу балки: ширина 120 мм, висота 180 мм. Виходячи з характеристик мінімального за нормами класу клеєної деревини GL24h, визначено теоретичну несучу здатність та прогин випробуваних балок. Розроблена методика та виконані випробування клеєних дерев'яних балок на згин, отримано залежності прогину від навантаження натурних клеєних дерев'яних балок під дією зосередженого навантаження в середині прольоту. Фактичний прогин балок склав 251 мм і 275 мм, що в 1,31 і 1,44 рази перевищує прогнозні значення прогину. Відповідно, руйнівне навантаження, визначене експериментально, в 1,96 і 2,03 рази перевищує теоретичне значення. Експериментальні значення руйнівного навантаження та прогину балок перевищили прогнозні теоретичні значення. При проведенні випробувань були досліджені особливості деформування і характер руйнування балок. При цьому визначальним фактором є наявність дефектів деревини і стиків ламелей по довжині в найбільш напружених шарах. З урахуванням отриманих даних наведені рекомендації по виготовленню, спрямовані на підвищення міцності клеєних балок з деревини на згин.
Ключові слова: клеєна дерев'яна балка, згин, руйнівне навантаження, прогин

S. Shekhorkina, K. Shliakhov, A. Sopilniak. **Experimental investigation of load-bearing capacity and deflections of full-scale glued laminated timber beams.** With the transition to the design of timber structures in accordance with European standards, problems arise in assessment of the load-bearing capacity of glued timber structures that are caused by insufficient amount of data about the physical, mechanical and deformation properties of glued timber, which is produced in Ukraine. The aim of the work was to determine the load bearing capacity in bending and deflection of a glued timber beam under the action of a concentrated load in the middle of the span. Two glued laminated timber beams were used in the experiment. Both beams were made using lumber from pine wood and a moisture-curing one-component polyurethane adhesive Kleiberit PUR 510 FiberBond. The beams have the dimensions of the cross-section: width of 120 mm and height of 180 mm. The length of the beams was 9880 mm. Each beam consisted of 9 layers of 20 mm thick lamellas glued together. Considering the absence of the data on the strength class of the beam material, the theoretical load bearing capacity and deflection were determined according to the characteristics of the GL24h class (minimum strength class), and amounted to 722 kgf and 19.1 cm, respectively. As a result of the tests, the failure load and the deflection of the beams were determined, and the dependences of the deflection on the load were obtained. The actual deflection of the beams determined was 251 mm and 275 mm, which is 1.31 and 1.44 times higher than the predicted deflection. Accordingly, the failure load determined experimentally is 1.96 and 2.03 times higher than the theoretical value. During the tests, the features of the deformation and the nature of the destruction of the beams were investigated. Wherein, the determining factor was the presence of defects in timber and lamellas joints along the length in the most stressed layers. Based on the data obtained, recommendations on manufacturing aimed at the increasing the bending strength of glued laminated timber beams are given. The results obtained will be further used in the development of structural solutions for hybrid timber-concrete floors.
Keywords: glued laminated timber beam, bending, failure load, deflection

DOI: 10.15276/opu.2.61.2020.01

ISSN 2076-2429 (print)
ISSN 2223-3814 (online)

Introduction

Structural glued wood is an engineering product that consists of two or more layers of sorted wood (lamellae) glued together lengthwise (along the fibers) [1]. Wood of almost all breeds can be used as lamellas for production of glued wood. In Ukraine it is most often pine wood [2, 3]. The main advantage of glued beams in relation to solid wood is the ability to obtain a product with predictable properties by sorting and cutting defects from lumber. Due to its high physical and mechanical properties, glued wood is used both for standard structures (for example, beams or columns) and for long-span flat or spatial structures. Glulam has a number of advantages over solid wood. These are higher strength and rigidity, dimensional stability, a variety of cross-sectional shapes and contours of the structure [3, 4, 5]. The wood is suitable for bioprocessing and recycling. Energy costs for the production of glued wood are much lower than for traditional concrete and steel [6]. Thus, glued wood is a promising structural material.

In Ukraine, glued wooden structures are well known and are used both in low-rise private construction and in the construction of public buildings and structures. Bent structures with various curvature are also made from glued wood. However, with the transition to design according to European standards [1] there are problems in assessing the load-bearing capacity of glued wooden structures. The problems are related to non-compliance by domestic manufacturers with the requirements for sorting lumber by quality and strength, insufficient data on the physical, mechanical and deformation properties of glued beams manufactured in Ukraine.

Analysis of publications and problem statement

Many domestic and foreign scientists have been engaged in experimental research of glued wood. The authors [7] conducted experimental studies and presented the results of tests of dry glued wood made of first grade pine and modified glued wood. In [8] the results of research of bearing capacity and fire resistance of wooden beams reinforced with external tape reinforcement are given. By comparison with the test results of non-reinforced beams, it is shown that the use of reinforcement can almost double the load-bearing capacity. The article [9] presents the methodology and results of the study of wooden board beams reinforced with metal and non-metal reinforcement. The authors [10] investigate the nature of deformation and strength of glued beams, and compare the results of tests of beams made of solid beams. The number of lamellae, types of adhesive materials and the presence of reinforcement of seams between layers of wood varied in the tested samples. In [11], the authors present the methodology and results of studies of glued wooden beams with a known location of defects (knots) on the bend in order to assess their impact on the mechanism of destruction, formation and development of cracks.

However, most tests of glued wood are performed on laboratory samples of limited length, while no less interesting is the work of natural structural elements under load.

Purpose: to determine the load-bearing capacity of the glued wooden beam under the action of a concentrated load in the middle of the span. To achieve this goal, the following tasks were solved: determination of theoretical load-bearing capacity, development of installation and test scheme for glued wooden beams; comparative analysis of theoretical and experimental bearing capacity and deflection.

Materials and methods of research

Two glued wooden beams made of pine wood and moisture-curing 1-component polyurethane adhesive Kleiberit PUR 510 FiberBond were used for the study.

Dimensions of the cross section of the beam: width 120 mm, height 180 mm. Beam length 9880 mm. Each beam consisted of 9 layers, glued together slats (boards) 20 mm thick. The wood of the slats is pine. Humidity of wood is 8…10 %.

To determine the predicted destructive load, the calculation of the theoretical load-bearing capacity of the glued beam, as well as the theoretical deflection in accordance with the requirements [1]. As the manufacturer did not provide information on the strength class and physical and mechanical characteristics of glued wood, the calculation was performed on the assumption that the glued wood corresponds to class GL24h, the strength and elasticity characteristics of which are given in Table 1.

Table 1

Characteristics of glued wood class GL24h for determining the theoretical load-bearing capacity [1]

Name of the characteristic	Symbol	Numerical value
Bending strength, MPa	$f_{m,g,k}$	24
The modulus of elasticity, MPa	$E_{0,g,mean}$	11500

The beam is a single-span articulated structure, which is subjected to a concentrated load. The design scheme of the beam is shown in Fig. 1. The test scheme is shown in Fig. 2.

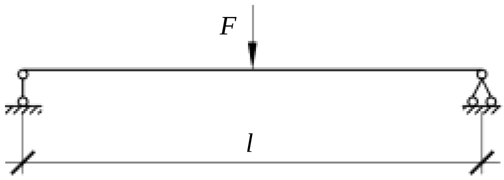

Fig. 1. Calculation scheme of the beam

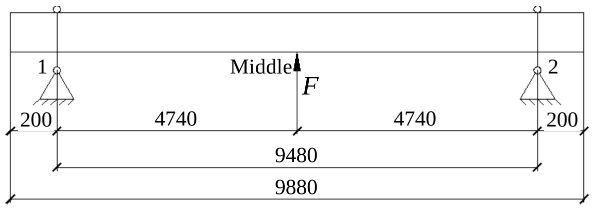

Fig. 2. Beam test scheme

Maximum bending moment in dangerous section:

$$M = Fl / 4, \quad (1)$$

where F is the concentrated load;

l – estimated span, m.

Equating the normal stresses in the dangerous cross section of the beam to the bending strength of glued wood, the theoretical destructive load on the beam can be determined:

$$F_{teor} = 4k_h \cdot f_{m,g,k} \cdot W / l, \quad (2)$$

where k_h – dimensional coefficient (for elements with a cross-sectional height less than 600 mm k_h=1.1);

W is the moment of resistance of the cross section of the beam.

Estimated beam deflection for the adopted load scheme:

$$f_{teor} = F_{teor} \cdot l^3 / (48\, E_{0,g,mean}\, I), \quad (3)$$

where I – the moment of inertia of the cross section of the beam.

The theoretical destructive load on the beam is F_{teor}=722 kgf, the estimated deflection of the beam f_{teor}=19.1 cm.

The test of glued wooden beams for bending was performed in accordance with the requirements [12]. The beam was fastened at both ends on hinged supports with the help of steel cables. The concentrated load on the beam was transferred in the middle of the span through the traverse by a hydraulic press. The stability of the beam from the plane of bending during loading was provided by a traverse mounted on the beam perpendicular to its longitudinal axis and freely sliding along the vertical racks parallel to the load line. During the tests, a hydraulic jack DG-50 was used, which provides a load of up to 50 tons. Oil was injected into the system manually using an oil station. Displacement measurements were performed with a tape measure using a STENLEY laser horizon, measurement accuracy ±1 mm.

The loading of the beam was carried out in three ranges smoothly within each to the destruction of the sample. Displacement readings were taken every two units of pressure on a manometer scale, which is approximately 200 kgf load, which corresponds to ≈10 % of the accepted value of the theoretical destructive load.

During the tests, the following indicators were recorded: the amount of load; the amount of displacement of each support and the point of application of the load (middle support); load and deflection at the time of failure. The primary signs of destruction of structures were also recorded: characteristic cracking, appearance of cracks, peeling of lamellae and others. The general view of the beam in the process of testing is shown in Fig. 3.

ISSN 2076-2429 (print)
ISSN 2223-3814 (online)

Fig. 3. Beam in the process of testing

Research results

The destruction of the beams took place in the stretched zone at the site of maximum bending moment. At a load of approximately 1000…1100 kgf in both cases, the lamellae began to peel off, which was accompanied by a characteristic crack and the appearance of cracks. The peculiarity of the beam № 1 was the localization in the stretched zone of several “plugs”, which in the manufacture of the beam replaced wood defects (dead knots). As a result, the destruction of the first beam began with the peeling of wooden “plugs”. A further increase in load caused the rupture of the wood fibers of the slats that lay below. The destruction of the beam № 2 began with the stratification of the upper lamella along the annual layers of wood in the joint zone along the length of the lamellae of the most stretched layer. The final failure occurred as a result of the rupture of the stretched wood fibers and the stratification of the lamellae closer to the place of application of the concentrated load, where the maximum bending moment acted. The nature of the destruction of the tested beams is shown in Fig. 4.

The destructive load and the amount of deflection of the beams are given in Table 2. Comparative characteristics of deflection and destructive load of beams, determined theoretically and experimentally, are given in Table 3. According to the obtained data, graphs of the dependence of deflection on load were constructed for both tested samples, which also show the point of failure by theoretical calculation (Fig. 5).

Table 2

Test results of beams

Sample number	Destructive load, kgf	Deflection at the time of failure, mm
Beam № 1	1469	251
Beam № 2	1413	275

a *b*

Fig. 4. The nature of the destruction of the tested beams №1 (a) and №2 (b)

Table 3

Comparative characteristics of deflection and destructive load of beams

Test series	Deflection, mm		Strength Coefficient	Destructive load, kgf		Strength Coefficient
	theor.	fact.		theor.	fact.	
Beam №1	191	251	1.31	722	1469	2.03
Beam №2		275	1.44		1413	1.96

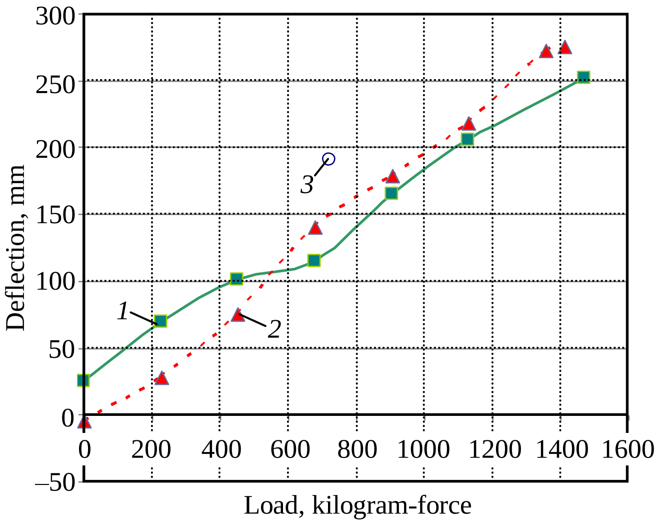

Fig. 5. Graphs of the dependence of the deflection on the load for the tested beams:
1 – beam 1; 2 – beam 2; 3 – theoretical

As can be seen from the obtained data, the actual deflection of the beams is 251 mm and 275 mm, which is 1.31 and 1.44 times higher than the predicted values of deflection. Accordingly, the destructive load determined experimentally is 1.96 and 2.03 times higher than theoretically determined. The properties of both samples turned out to be quite similar, but the beam № 2 showed less resistance to bending load than the beam № 1, which manifested itself in greater deflection and less destructive loading force. Graphs of dependence of deflection on load have insignificant deviations from the rectilinear law.

The beginning of the destruction was caused by a certain concentration of wood defects near the place of action of the maximum bending moment, but the nature of the destruction was different. If the beam № 1 began to collapse at the location of several plugs in the most stretched lamella, the weakest point of the beam № 2 was the joint of the lamellae in the second layer and the large angle of the annual layers in the upper lamella (Fig. 4*b*). Given the above, to increase the bending strength of glued wood beams, it is recommended to avoid the presence of wood defects and joints of the slats in the most stretched layers near the place of maximum bending moment.

Conclusions

A series of tests of load-bearing capacity for bending and deflection under the action of concentrated load in the middle of the span of full-size wooden glued beams made of pine wood lumber and polyurethane glue Clauberite PUR 510 FiberBond. The sizes of beams are 120×180×9880 mm (b×h×l).

Based on the characteristics of strength and elasticity for glued wood of the minimum class GL24h, the theoretical load-bearing capacity and deflection of the tested beams are determined. According to the results of the experiment, the actual destructive load was established, which is 1.96 and 2.03 times higher than theoretically determined. The experimentally determined deflection of the beams is 1.31 and 1.44 times higher than the theoretical values.

ISSN 2076-2429 (print)
ISSN 2223-3814 (online)

During the tests the peculiarities of deformation and the nature of beam fracture were investigated. The determining factor is the presence of wood defects and joints of the slats along the length in the most stressed layers. Taking into account the obtained data, manufacturing recommendations aimed at increasing the bending strength of glued wood beams are given.

Література

1. ДБН В.2.6-161:2017. Дерев’яні конструкції. Основні положення [чинні від 2018-01-02]. Вид. офіц. Київ : Мінрегіон України, 2017. 111 с. (Державні будівельні норми України).
2. Кліменко В.З. Ефективний конструкційний матеріал – клеєна деревина. *Будівництво України.* 2009. Вип. 9/10. С. 16–20.
3. Калугин А.В. Клееные деревянные конструкции в современном строительстве. *Промышленное и гражданское строительство*. 2011. Вип. 7(2). С. 32–37.
4. Турковский С.Б., Погорельцев А.А., Преображенская И.П. Клееные деревянные конструкции с узлами на вклеенных стержнях в современном строительстве (система ЦНИИСК). М. : РИФ «СТРОЙМАТЕРИАЛЫ», 2013. 308 с. URL: https://lesprominform.ru/jarticles.html?id=3581 (дата звернення: 20.03.2020).
5. Kuzman M., Oblak L., Vratuša S. Glued Laminated Timber in Architecture. Drvna industrija. 2010. Vol. 61. URL: https://www.researchgate.net/publication/46401414 _Glued_Laminated_Timber_in_ Architecture (дата звернення: 20.03.2020).
6. Harris R. Engineered timber structures in the UK. 3rd Forum International Bois Construction, 2013 pp. 1–12. URL: http://www.forum-boisconstruction.com /conferences/FBC_2013_Harris.pdf (дата звернення: 20.03.2020).
7. Гомон С.С., Гомон С.С., Зінчук А.В. Дослідження модифікованої силором клеєної деревини на стиск вздовж волокон. *Вісті Донецького гірничого інституту*. 2017. № 1. С. 134–138. URL: http://nbuv.gov.ua/UJRN/Vdgi_2017_1_21 (дата звернення: 20.03.2020).
8. Башинський О.І., Боднарчук Т.Б., Пелешко М.З. Несуча здатність та вогнестійкість дерев’яних балок армованих зовнішньою стрічковою арматурою. *Вісник Львівського державного університету безпеки життєдіяльності.* 2014. № 9. С. 184–189. URL: http://nbuv.gov.ua/UJRN/ Vldubzh_2014_9_27 (дата звернення: 20.03.2020).
9. Експериментальне дослідження роботи дощатоклеєних балок, армованих металевою та неметалевою арматурою. / Б.Г. Демчина, Т.Й. Бляхар, А.Р. Кравз, Д.О. Орешкин, М.І. Сурмай. *Вісник Національного університету "Львівська політехніка". Теорія і практика будівництва.* 2011. № 697. С. 87–92. URL: http://ena.lp.edu.ua:8080/handle/ntb/10395 (дата звернення: 20.03.2020).
10. Uzel M., Togay A., Anil Ö., Söğütlü C. Experimental investigation of flexural behavior of glulam beams reinforced with different bonding surface materials. *Construction and Building Materials.* 2018. 158. 149–163. DOI:10.1016/j.conbuildmat.2017.10.033.
11. Kandler G., Lukacevic M. Füssl J. Experimental study on glued laminated timber beams with well-known knot morphology. *Eur. J. Wood Prod.* 2018. 76. 1435–1452. DOI: https://doi.org/10.1007/ s00107-018-1328-6.
12. ДСТУ EN 408:2003. Лісоматеріали конструкційні. Конструкційна та клеєна шарувата деревина. Визначення деяких фізичних та механічних властивостей [чинні від 01.07.2009]. Вид. офіц. Київ : Мінрегіон України, 2009. URL: http://online.budstandart.com/ua/catalog/doc-page.html?id_ doc=66659 (дата звернення: 20.03.2020).

References

1. DBN B.2.6-161:2017. Timber structures. General aspects. (2017). Kyiv : Ministry of Regional Construction of Ukraine, 111 p.
2. Klimenko, V.Z. (2009). Effective structural material – glued timber. *Budivnitstvo Ukrainy : Naukovo-vyrobnychiy jurnal, 9/10,* 16–20.
3. Kalugin, A.V. (2011). Glued timber structures in modern construction. *Promyshlennoye s grazhdanskoye stroitelstvo, 7(2),* 32–37.
4. Turkovskiy, S.B., Pogorelcev, A.A., & Preobrajenkaya, I.P. (2013). *Glued timber structures with joints with glued-in rods in modern construction (system of CNIISK)*. Moscow: RIF «Stroymaterialy». URL: https://lesprominform.ru/jarticles.html?id=3581.
5. Kuzman, M., Oblak, L., & Vratuša, S. (2010). Glued Laminated Timber in Architecture. *Drvna industrija, 61(3),* 197–204. URL: https://hrcak.srce.hr/file/88694.

6. Harris, R. (2013). Engineered timber structures in the UK. *3rd Forum International Bois Construction*, 1–12. Retrieved from: http://www.forum-boisconstruction.com /conferences/FBC_2013_Harris.pdf.
7. Gomon, S.S., Gomon, S.S., & Zynchuk, A.B. (2017). Investigation of silage modified glued timber in compression along fibers. *Journal of Donetsk Mining Institute*, *1*, 134–138.
8. Bashynskyi, O.I., Bondarchuk, T.B., & Peleshko, M.Z. (2014). Bearing capacity and fire resistance of timber beams reinforced with external tape reinforcement. *Bulletin of Lviv State University of Life Safety*, *9*, 184–189.
9. Demchyna, B.G., Blyakhar, T.Y., Kravz, A.R., Oreshkin, D.O., & Surmay, M.I. (2011). Experimental study of the work of laminated beams reinforced with metal and non-metallic reinforcement. *Bulletin of Lviv Polytechnic National University, Construction theory and practice, 697,* 87–92. Retrieved from: http://ena.lp.edu.ua:8080/handle/ntb/10395.
10. Uzel, M., Togay, A., Anil, Ö., & Söğütlü, C. (2018). Experimental investigation of flexural behavior of glulam beams reinforced with different bonding surface materials. *Construction and Building Materials, 158*, 149–163. DOI: 10.1016/j.conbuildmat.2017.10.033.
11. Kandler, G., Lukacevic, M. & Füssl, J. (2018). Experimental study on glued laminated timber beams with well-known knot morphology. *Eur. J. Wood Prod. 76*, 1435–1452. DOI: https://doi.org/10.1007/s00107-018-1328-6.
12. DSTU EN 408:2003. Timber structures. Structural timber and glued laminated timber – Determination of some physical and mechanical properties. (2009). Kyiv: Minregion Ukrainy.

Шехоркіна Світлана Євгеніївна; Shekhorkina Svitlana, ORCID: http://orcid.org/0000-0002-7799-2250
Шляхов Костянтин Валерійович; Shliakhov Kostiantyn, ORCID: http://orcid.org/0000-0001-6493-6201
Сопільняк Артем Михайлович; Sopilniak Artem, ORCID: http:// orcid.org/ 0000-0002-3067-0529

Received April 23, 2020

Accepted May 25, 2020