Zeszyty Naukowe Politechniki Częstochowskiej
Budownictwo
ISSN 0526-5916

Zeszyty Naukowe Politechniki Częstochowskiej nr 28 (2022), 21-26
DOI: 10.17512/znb.2022.1.03

# Influence of longitudinal composite reinforcement on the structural behavior of glued laminated timber with openings

Damian Jończyk[1], Yaroslav Blikharskyy[2]

**ABSTRACT:**
Glued laminated timber is now often used in construction. Most often, glued laminated timber is used to make load-bearing beams, in which there is often a need for architectural reasons to make openings for various types of installations. These openings weaken the stiffness. An increasingly common solution is to reinforce wooden beams with longitudinal composite elements. The paper presents numerical calculations analyzing the influence of longitudinal composite reinforcement in the form of BFRP bars on the deflection of glued laminated timber beams with openings.

**KEYWORDS:**
timber; glued laminated timber; FRP; reinforcement; holes

## 1. Introduction

Wood is a building material with high aesthetics. Consequently, it is now often used by architects. A particularly popular construction solution is glued laminated timber girders, allowing a lot of freedom in choosing the appropriate dimensions. Due to the size proportions used in the girders being relatively high, it is often necessary to make holes that result in a concentration of tensile stresses perpendicular to the fibers. In addition, the load-bearing capacity and stiffness are reduced, especially in the shear areas. Openings are often necessary for installation in order not to reduce the usable height of the room.

An extensive study of glued laminated timber with holes was presented [1, 2]. The research included literature, experimental, numerical and analytical research on girders with circular openings. Large holes, both round and square, were examined [3]. The research included experimental tests and an numerical analysis of crack propagation in places of stress concentration. An overview of the knowledge of glued laminated timber with openings has been presented by [4]. The main conclusion of the review was that there was no real-scale testing of wooden elements with openings, which in the case of wood is important due to the occurrence of the scale effect. In order to improve the structural behavior and load-bearing capacity of elements with openings, the use of reinforcement for the transverse reinforcement of openings [5-7] is tested.

Currently, more and more common is the use of glued laminated timber beams reinforced longitudinally with FRP (Fiber Reinforced Polymer) composites in various forms (tapes, mats, rods, cords) [8-11]. This reinforcement can be located not only in the tension zone, but also in the compression zone. However, there are no studies in the literature on how the use of

[1] Czestochowa University of Technology, Faculty of Civil Engineering, ul. Akademicka 3, 42-218 Częstochowa, Poland, e-mail: damian.jonczyk@pcz.pl, orcid id: 0000-0003-2161-4768
[2] Lviv Polytechnic National University, Department of Highways and Bridges, Lviv, 6 Karpinskoho St., Ukraine, e-mail: yaroslav.z.blikharskyy@lpnu.ua, orcid id: 0000-0002-3374-9195

longitudinal composite reinforcement (both in the tension and the compression zone) can affect the behavior of beams with openings.

The aim of the article is to determine the effect of longitudinal composite reinforcement used in glued laminated timber beams on the structural behavior of beams with openings. For the analysis, numerical calculations were performed using the Finite Element Method.

## 2. Materials and methods

### *2.1. Materials*

**Wood.** Wood is an anisotropic material. However, we can distinguish three main directions used for analyzes: longitudinal, tangent and radial (Fig. 1). Therefore, for numerical calculations, wood is assumed to be orthotropic. The wood work model was adopted as linear-elastic. The properties for the tangential and radial directions were assumed to be identical, because usually the method of making the beams does not allow to clearly distinguish these two directions. The class of wood for the analyzed examples was assumed as GL24h. Based on the adopted wood class, the material data presented in Table 1 was used for calculations.

**Composite bars.** The model for composite bars was assumed to be isotropic, linear-elastic. Material data is taken from laboratory test reports. The values adopted for the calculations are presented in Table 1.

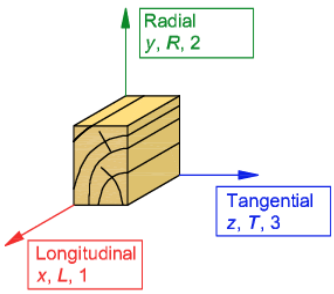


**Fig. 1.** Coordinate system adopted for numerical calculations

**Table 1**
Material data adopted in the numerical model [13-17]

| Characteristic | Unit | Timber | BFRP |
|---|---|---|---|
| Young's modulus | MPa | $E_L$ = 9600 | $E$ = 56 300 |
| | | $E_R = E_T$ = 250 | |
| Kirchhoff modulus | MPa | $G_{LR} = G_{LT} = G_{RT}$ = 540 | |
| Poisson's ratio | – | $\nu_{LR} = \nu_{LT} = \nu_{RT}$ = 0.41 | $\nu$ = 0.3 |

### *2.2. Methods*

The numerical model was made in the ANSYS Workbench 16.1 program. A four-point bending beam was adopted as a static scheme. In order to reduce the number of finite elements, and thus shorten the computational time, 1/4 of the beam was modeled directly in the program. The boundary conditions of the beam were modeled by means of steel flat bars to reflect the method of conducting experimental tests of this type of wooden elements. The supports were declared using the Remote Displacement function and the load using the Force function. The dimensions of the assumed calculation model were adopted to meet the requirements set out in the standard (PN-EN 408 + A1: 2012) [12]. The dimensions of the calculation scheme and the model used in the computer program are shown in Figure 2. The dimensions of the finite elements were determined as 1 cm. All contacts are modeled as Bonded (line contact).

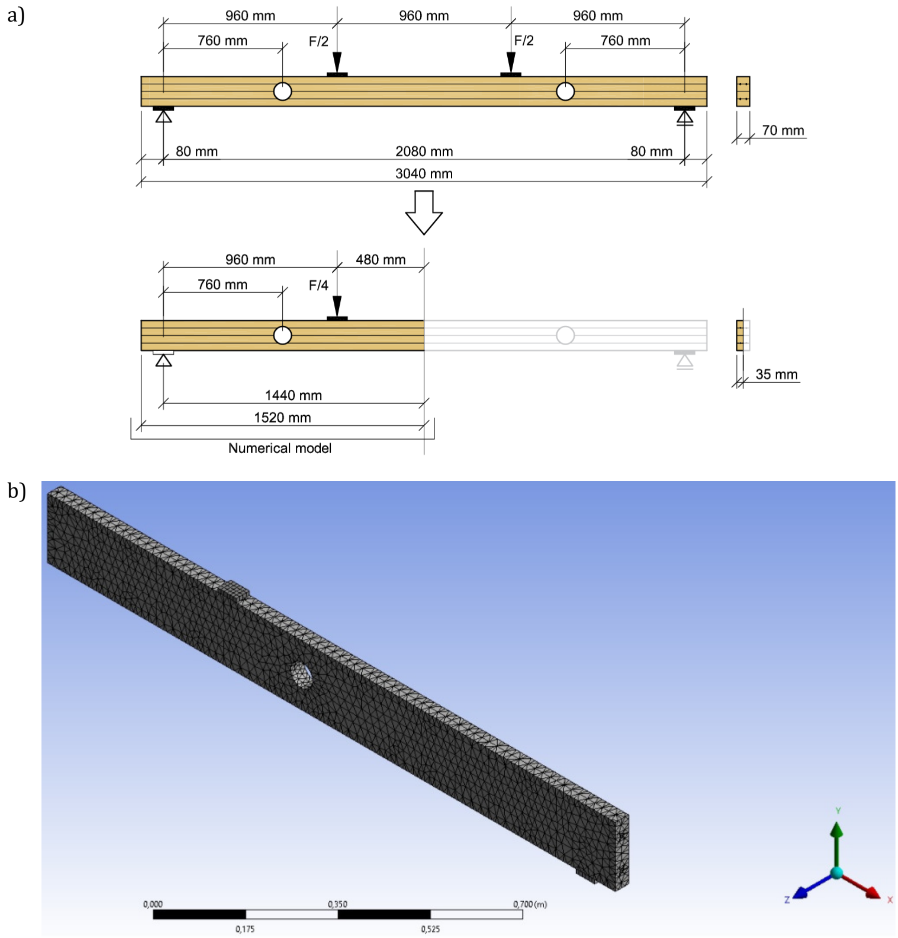


**Fig. 2.** Diagram of the calculated beams: a) static diagram, b) numerical model

Two heights of cross-sections, 160 mm and 280 mm, unreinforced and reinforced individually and twice with two basalt BFRP bars with a diameter of 9 mm, were used for the analysis. Round holes with a diameter of 100 mm were made for all the beams (Fig. 3).

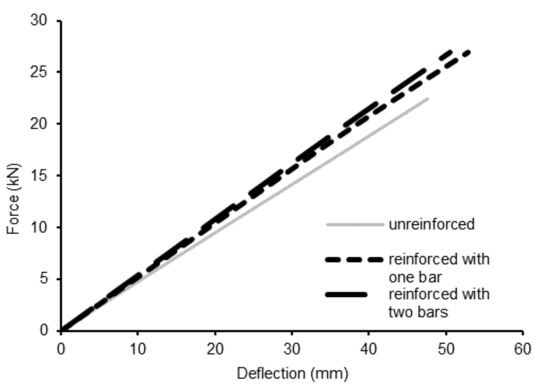


**Fig. 3.** Deflection / force diagram for beams with height 160 mm

## 3. Results

On the basis of numerical calculations, force deflection diagrams were presented. The diagram for beams with a height of 160 mm showing the beams: unreinforced, reinforced with one bar and two is shown in Figure 3. The diagram for beams with a height of 280 mm showing the beams: unreinforced, reinforced with one bar and two is shown in Figure 4. In addition, to illustrate the nature of the deflection, shown are deflection maps from the ANSYS program. The deflection map for a beam reinforced with two 160 mm high bars is shown in Figure 5, and for a 280 mm high beam is shown in Figure 6.

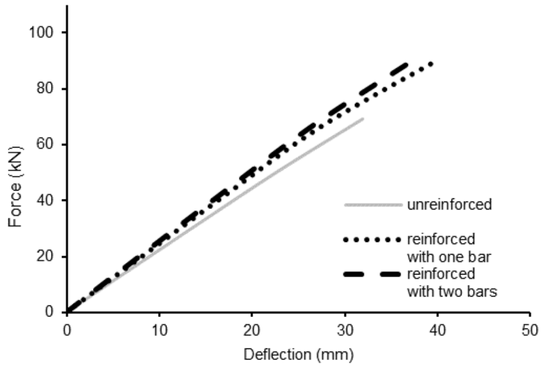


**Fig. 4.** Deflection / force diagram for beams with height 280 mm

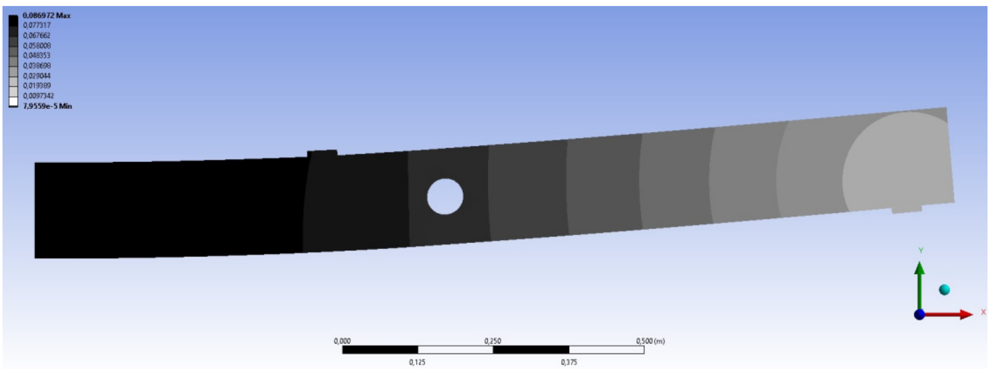


**Fig. 5.** Deflection of beam reinforced with two bars with height 160 mm

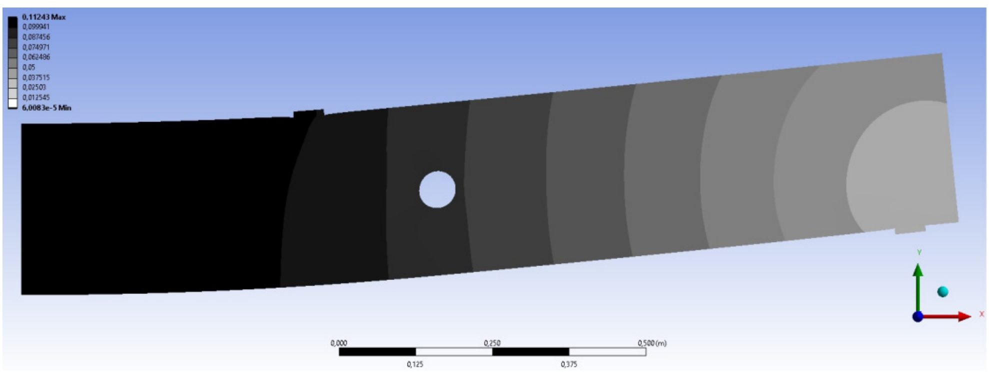


**Fig. 6.** Deflection of beam reinforced with two bars with height 280 mm

## 4. Discussion and conclusion

The article presents numerical calculations of glued laminated timber beams reinforced with composite longitudinal bars, additionally weakened by openings. The calculations were made for two beam heights of 160 mm and 280 mm. For both heights, three variants were adopted: unreinforced, single armored and double armored.

Figure 3 shows the equilibrium paths for all types of tested 160 mm high beams, while Figure 4 shows the equilibrium paths for 280 mm high beams. Figures 5 and 6 show the deflection maps from the ANSYS program for double-reinforced beams with a height of 160 mm and 280 mm, respectively.

The use of longitudinal composite bars reduces the deflection value of beams with openings, for both single and double reinforced sections. The reduction in deflection compared to the unreinforced 160 mm high beams is 8.5% and 12.3%, respectively, for single and double reinforced sections. The reduction in deflection for beams with a height of 280 mm is 9.5% and 13.3%, respectively, for beams with single and double reinforcement.

The reinforcement has a positive effect on the structural behavior of beams with openings. Longitudinal reinforcement can be used in beams with small openings. In the case of beams with large openings, it is more effective to use direct reinforcement of the openings. In further research, the influence of cracks in the vicinity of the holes should be examined, because the article does not consider this type of damage.

*Acknowledgment*

The authors are grateful for granting access to the computing infrastructure built in the projects No. POIG.02.03.00-00-028/08 "PLATON - Science Services Platform" and No. POIG.02.03.00-00-110/13 "Deploying high-availability, critical services in Metropolitan Area Networks (MAN-HA)".

## References

[1] Okamoto S., Akiyama N., Araki Y., Aoki K., Inayama M., Study on the strength of glued laminated timber beams with round holes: difference in structural performance between homogeneous-grade and heterogeneous-grade timber, Journal of Wood Science 2021, 67, 8.

[2] Okamoto S., Akiyama N., Araki Y., Aoki K., Inayama M., Study on the strength of glued laminated timber beams with round holes: proposal of the design formula for the splitting strength, Journal of Wood Science 2022, 68, 6.

[3] Karimi-Nobandegani A., Valipour H., Timber beams with openings: Laboratory testing and nonlocal finite element modelling, Engineering Structures 2021, 245(10), 112867.

[4] Jeleč M., Varevac D., Zovkić J., Glulam beams with holes, Electronic Journal of the Faculty of Civil Engineering Osijek 2014, 9, 22-33.

[5] Ardalany M., Fragiacomo M., Carradine D., Moss P., Experimental behavior of Laminated Veneer Lumber (LVL) joists with holes and different methods of reinforcement, Engineering Structures 2013, 56, 2154-2164.

[6] Ilić L., Unreinforced and reinforced openings in glt beams a comparison based on experimental investigations, Master thesis, Graz 2017.

[7] Pełczyński J., Brodniewicz P., Sabouni-Zawadzka A., Gilewski W., Design and modeling of glulam beams with holes, IOP Conf. Series: Materials Science and Engineering, 1015, 012026.

[8] Fossetti M., Minafò G., Papia M., Flexural behaviour of glulam timber beams reinforced with FRP cords, Construction and Building Materials 2015, 95, 54-64.

[9] Yang H., Liu W., Lu W., Zhu S., Geng Q., Flexural behavior of FRP and steel reinforced glulam beams: Experimental and theoretical evaluation, Construction and Building Materials 2016, 106, 550-563.

[10] Vahedian A., Shrestha R., Crews K., Experimental and analytical investigation on CFRP strengthened glulam laminated timber beams: Full-scale experiments, Composites Part B 2019, 164, 377-389.

[11] Rajczyk M., Jończyk D., Behavior of glulam beams strengthened with BFRP bars, Materials Science and Engineering 2019, 603, 1-9.

[12] PN-EN 408+A1:2012 Konstrukcje drewniane – Drewno konstrukcyjne lite i klejone warstwowo. Oznaczenie niektórych właściwości fizycznych i mechanicznych.

[13] Nowak T., Jasieńko J., Czepiżak, D., Experimental tests and numerical analysis of historic bent timber elements reinforced with CFRP strip, Construction and Building Materials 2013, 40, 197-206.

[14] Rajczyk, M., Jończyk, D., Badania belek z drewna klejonego warstwowo wzmocnionych prętami bazaltowo--epoksydowymi, Zeszyty Naukowe Politechniki Częstochowskiej 2018, 174, Budownictwo z. 24, 298-304.

[15] Kamińska M., Szymczak P., Olbryk P., Badanie prętów kompozytowych. Sprawozdanie z badań, Laboratorium Badawcze Materiałów i Konstrukcji Budowlanych Politechniki Łódzkiej, Łódź 2012.

[16] Kamińska M., Szymczak P., Olbryk P., Chołostiakow S., Badanie betonowych belek zbrojonych prętami kompozytowymi. Sprawozdanie z badań, Laboratorium Badawcze Materiałów i Konstrukcji Budowlanych Politechniki Łódzkiej, Łódź 2012.

[17] Kamińska M., Szymczak P., Olbryk P., Chołostiakow Sz., Badanie przyczepności prętów kompozytowych GFRP i BFRP do betonu. Sprawozdanie z badań, Laboratorium Badawcze Materiałów i Konstrukcji Budowlanych Politechniki Łódzkiej, Łódź 2013.

## Wpływ podłużnego zbrojenia kompozytowego na pracę statyczną belek z drewna klejonego z otworami

**STRESZCZENIE:**
Drewno klejone warstwowo jest obecnie często wykorzystywane w budownictwie. Najczęściej z drewna klejonego warstwowo wykonywane są dźwigary nośne, w których często ze względów architektonicznych istnieje potrzeba wykonania otworów pod różnego rodzaju instalacje. Otwory te osłabiają sztywność. Coraz bardziej powszechnym rozwiązaniem jest wzmacnianie belek drewnianych podłużnymi elementami kompozytowymi. W artykule przeprowadzono obliczenia numeryczne analizujące wpływ podłużnego zbrojenia kompozytowego w formie prętów BFRP na ugięcie belek z drewna klejonego z otworami.

**SŁOWA KLUCZOWE:**
drewno; drewno klejone warstwowo; FRP; zbrojenie; otwory