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Designing reinforced plywood panels through deformation methods

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Abstract

A deformation methodology for theoretical and mathematical modelling and calculation of composite-reinforced plywood panels is proposed. The stages of the stress-strain state of a reinforced bending wooden element (plywood panel) with metal reinforcement are presented. An algorithm for constructing a 'moment-curvature' graph of a reinforced wooden element (plywood panel) is proposed.

Keywords: reinforcement; concrete; stress-strain state; tension; destruction; anchoring, strength

1. Introduction

Wood is widely used in construction (Aleksiievets et al. (2024), Madsen (1974), Homon et al. (2024), Sinha et al. (2012)). The main advantages of wood are its high strength (Homon et al. (2024), De la Rosa García et al. (2013), Yasniy et al. (2022), Galicki and Czech (2005)), light weight, ease of structures processing and manufacturing, environmental friendliness and high aesthetic characteristics (Datsiuk et al. (2024), Green and Kretschmann (1992), Landis et al. (2002)). It is often used in aggressive environments (Huang et al. (2006), Homon et al. (2024), Janiak et al. (2024), Homon et al. (2023), Roshchuk et al. (2024)). In many cases, wooden elements are used as load-bearing

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structures in the design of civil and industrial buildings (Anshari et al (2017), Gomon et al. (2022), Nsouami et al. (2022), Pavluk et al. (2023)). These include beams (Gomon et al. (2022), Wdowiak-Postulak (2020), Mykhailovskyi et al. (2024), Sobczak-Piastka et al. (2023), Zhao et al. (2020)), arches, trusses, columns, frames, panels (Mykhailovskyi (2021)), and others. They can be solid or glued (Sobczak-Piastka et al. (2020), Donadon et al. (2020), Soriano et al. (2016), Anshari et al (2017)).

Nomenclature

N_x	forces acting along the bending element
M_z	uniformly distributed load
$N_{w,c}, N_{w,t}$	internal forces acting in the compressed and stretched zone of wood
$N_{s,c}$	forces arising in a compressed reinforcing bar
$N_{s,t}$	forces arising in a tensile carbon tape
$N_{plw,c}$	forces arising in a compressed plywood
$N_{plw,t}$	forces arising in a tensile plywood
M_i	external bending moment acting on the cross section
N_i	external force acting along the neutral line
h	beam height
b	beam width
$M_{w,c}, M_{w,t}$	internal moments acting in the compressed and stretched zone of wood
y_c, y_t	height of the compressed and stretched zone of wood in the cross section
$u_{w,c}, u_{w,t}$	extreme deformations occurring at the edges of the cross-section of a wooden beam
$f_{w,c}(u_{w,c}), f_{w,t}(u_t)$	wood deformation functions (dependence of stresses on deformations)
$M_{s,c}$, $M_{s,t}$	moment perceived by a compressed and tensile reinforcement bar
$M_{plw,c}$, $M_{plw,t}$	moment perceived by a compressed and tensile plywood
$A_{s,c}$	cross-sectional area of compressed reinforcement
$A_{s,t}$	cross-sectional area of tensile reinforcement
$f_{s,c}(u_{s,c})$	function of deformation of compressed reinforcement
$f_{s,t}(u_{s,t})$	function of deformation of tensile reinforcement
$y_{s,c}$	distance from the neutral line to the center of the compressed and tensile reinforcement

Structural strength is achieved by calculating various types of external impacts, as outlined in DBN B.2.6-161 (2017), Eurocode 5 (2004), and studies by Gomon et al. (2024), Pavluk et al. (2024), and Mykhailovskyi et al. (2022). Stiffness is established through detailed analyses of deflections and displacements, as demonstrated by Gomon et al. (2023). Reliability is ensured via mathematical modeling of operations.

One of the primary concerns for many researchers is the enhancement of stiffness in wooden elements and structures, as noted by Vahedian et al. (2019), Rescavlo et al. (2020), and Soriano et al. (2016). In our previous scientific studies, we addressed this issue concerning solid and glued beams (Gomon et al. (2024), Sobczak-Piastka et al. (2020), Gomon et al. (2022)).

A key objective in designing plywood panels is to achieve material savings. Accordingly, this article presents a contemporary approach to modelling the performance of plywood panels based on a deformation model. Additionally, the paper outlines the foundation for numerical modelling aimed at increasing the stiffness of plywood panels through the use of steel reinforcement and carbon tape.

Construction of a plywood panel is shown in Fig. 1.

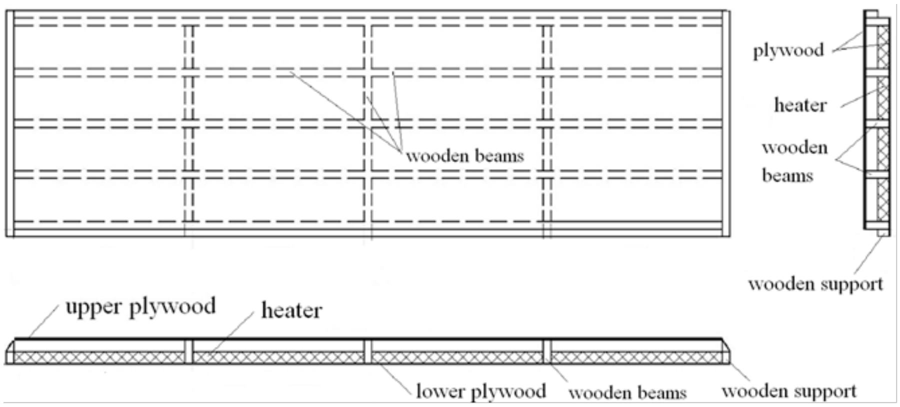

Fig. 1. Construction of a plywood panel

2. Methods of experimental research

To design a plywood panel, it is necessary to determine its stress-strain state. Fig. 2 shows the stress-strain state in the central part of the panel, where the greatest bending moment occurs. The system of equilibrium equations and all the necessary equations to determine the internal forces are as follows:

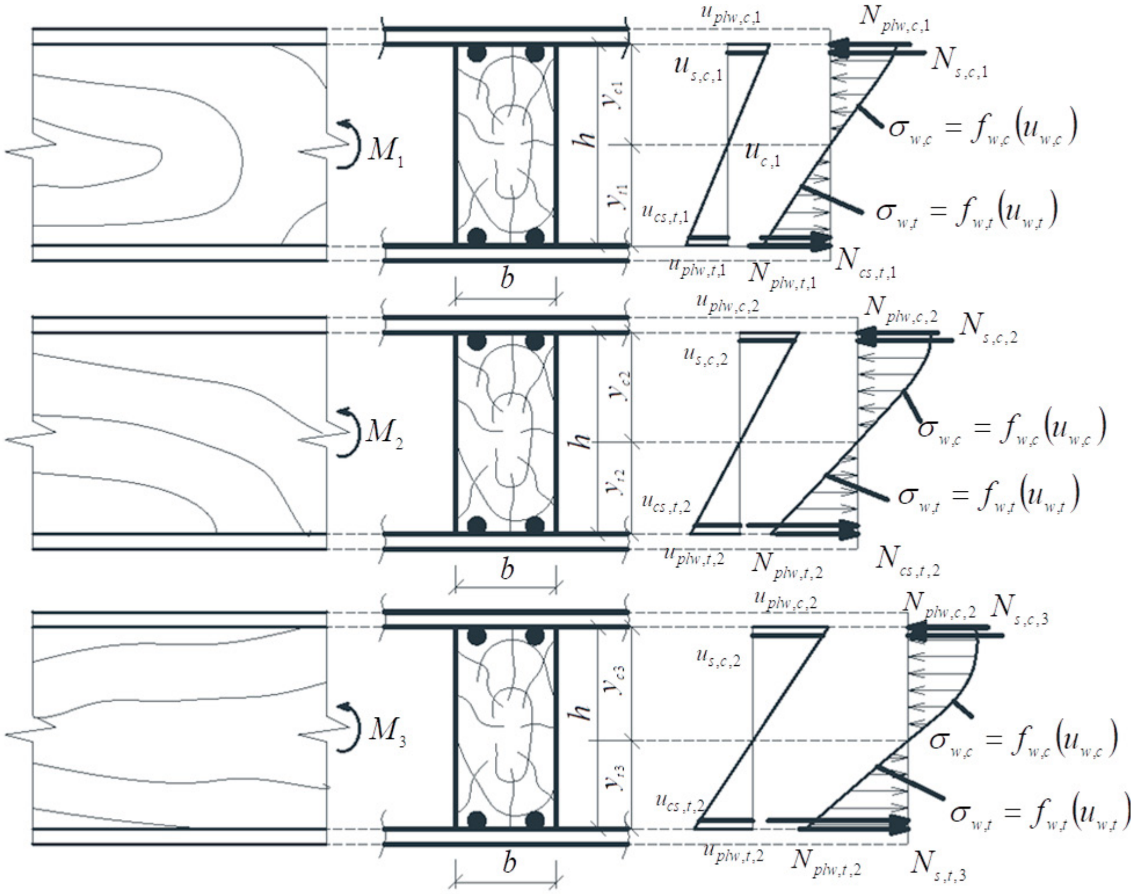

Fig. 2. Stages of the stress-strain state of a reinforced bending wooden element (plywood panel) with metal reinforcement

$$\begin{cases}\sum N_{x,arm} = 0; \\ \sum M_{z,arm} = 0; \end{cases} \tag{1}$$

Equilibrium equations for determining the forces in the cross-section

$$\begin{cases} N_{w,c} + N_{s,c} + N_{plw,c} - N_{w,t} - N_{s,t} - N_{plw,t} = 0 \\ M_i - M_{w,c} - M_{w,t} - M_{s,c} - M_{s,t} - M_{plw,c} - M_{plw,t} = 0 \end{cases} \tag{2}$$

Internal forces and moments arising in the normal section of a bending element with consideration of deformation functions of wood and reinforcement

$$N_{w,c} = b \cdot y_c \int_0^{u_c} f_{w,c}(u_{w,c}) \frac{1}{u_c} du - A_{s,c} f_{w,c}(u_{s,c}) \tag{3}$$

$$N_{w,t} = b \cdot y_t \int_0^{u_t} f_{w,t}(u_{w,t}) \frac{1}{u_t} du - A_{s,t} f_{w,t}(u_{s,t}) \tag{4}$$

$$M_{w,c} = b \cdot y_c{}^2 \int_0^{u_c} \frac{u_{w,c}}{u_c{}^2} f_{w,c}(u_{w,c}) du - A_{s,c} f_{w,c}(u_{s,c}) y_{s,c} \tag{5}$$

$$M_{w,t} = b \cdot y_t{}^2 \int_0^{u_t} \frac{u_{w,t}}{u_t{}^2} f_{w,t}(u_{w,t}) du - A_{s,t} f_{w,t}(u_{s,t}) y_{s,t} \ . \tag{6}$$

The magnitude of internal forces perceived by the metal reinforcement and the forces perceived by the plywood in the compressed and tensile zones will be equal to

$$N_{s,c} = A_{s,c} f_{s,c}(u_{s,c}) \tag{7}$$

$$N_{s,t} = A_{s,t} f_{s,t}(u_{s,t}) \tag{8}$$

$$N_{plw,c} = A_{plw,c} f_{plw,c}(u_{plw,c}) \tag{9}$$

$$N_{plw,t} = A_{plw,t} f_{plw,t}(u_{plw,t}) \tag{10}$$

The value of the bending element perceived by the reinforcement and plywood in the compressed and tensile zones will be equal to

$$M_{s,c} = N_{s,c} y_{s,c} \tag{11}$$

$$M_{s,t} = N_{s,t} y_{s,t} \tag{12}$$

$$M_{plw,c} = N_{plw,c} y_{plw,c} \quad (13)$$

$$M_{plw,t} = N_{plw,t} y_{plw,t} \quad (14)$$

The design of the glued plywood panel should be based on the stiffness and strength of the structure. To perform the calculation, it is necessary to determine the strength of the panel at the maximum bending moment, as well as under the action of shear stresses. Figure 3 shows the algorithm for determining the curvature versus moment. By substituting the curvature and gradually increasing it, the maximum bending moment corresponding to the failure of the structure is determined. In addition, the graph of moment versus curvature can be used to determine the shear stress and deflection of a structure.

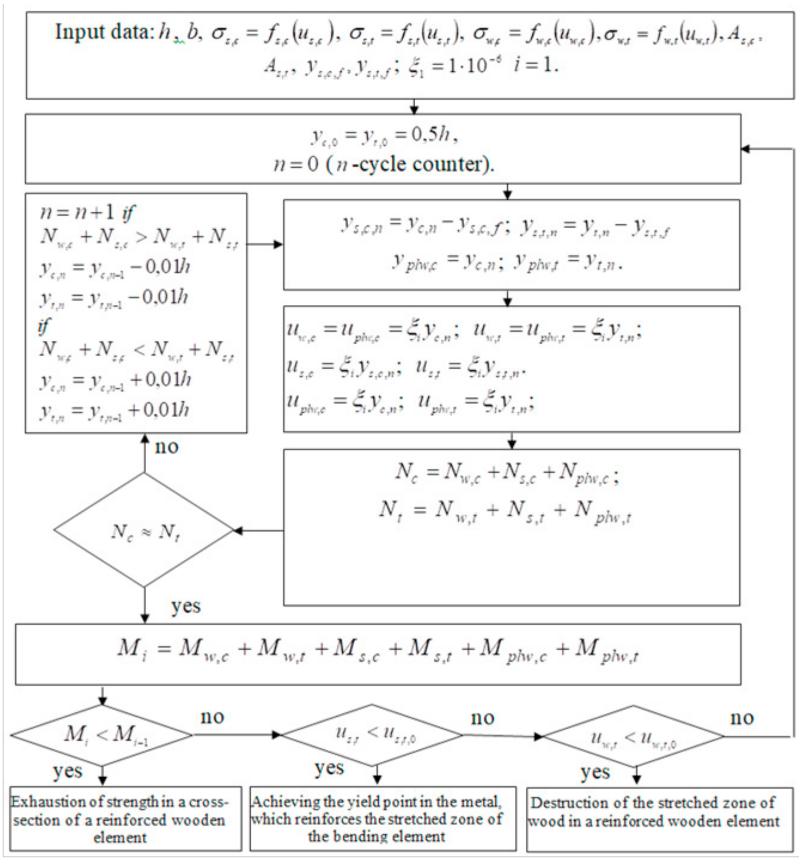

Fig. 3. Algorithm for constructing a moment-curvature graph of a reinforced wooden element (plywood panel)

3. Conclusions

1. A deformation methodology for theoretical and mathematical modelling and calculation of composite-reinforced plywood panels is proposed. This deformation model serves as a foundational aspect of understanding the behaviour of elastoplastic elements made from wood.
2. Analyzing the stress-strain state of a reinforced plywood panel elevates the modelling and calculation processes, incorporating the nonlinear deformation characteristics of wood.

3. Current standards typically focus on determining only the limit states of glued plywood panels. However, incorporating the stress-strain state into the analysis can enhance our ability to predict the material's performance throughout its production, use, and eventual degradation. This deformation model broadens our understanding of how plywood panels function and enables the design of panels with prestressed metal reinforcement.

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