# METHOD (ALGORITHM) FOR A NUMERICAL AND GRAPHIC DETERMINATION OF STIFFNESS IN BENDING OF STRUCTURAL PARTICLEBOARDS

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## ABSTRACT

The algorithm refers to a nomogram for numerical and graphic determination of stiffness in bending of structural particleboards (SPBs). SPBs are technologically formed composite wood-based products with standardised designation P6 with wide application in construction, furniture manufacturing and interior. As evaluation criterion for the load-carrying capacity of the boards, i.e. for their fitness for use in various structural solutions, serves their strain-strength index stiffness in bending St, defined in technical literature as a product of the inertia moment of the cross-section Jy and the modulus of elasticity in bending Em. For the time being, in engineering calculations, only indirect estimates for this index on the basis of the values for the modulus of elasticity in bending are used.

The algorithm for numerical and graphic determination of stiffness in bending of SPBs is based on:

- the physical nature of the composite as technologically formed layered material and the simulation modelling of its cross-section as a “double T beam”;
- the experimentally established empirical dependences of the modulus of elasticity in bending on the bulk densities of the composite board and the wood raw material.

**Key words:** algorithm, stiffness in bending, modulus of elastisity in bending, bulk density, composite, inertia moment.

## INTRODUCTION

The algorithm refers to a nomogram for numerical and graphic determination of stiffness in bending of structural particleboards (SPBs). The stiffness of the structural materials characterises their strain-strength properties and its numerical estimate must be taken into account when determining the load-carrying capacity of materials in specific engineering solutions. For the purpose, the application of an express numerical method satisfying the requirements for accuracy of the stiffness values mainly of composite boards with standardised designations P6 and P7, that are intended for use above all as floors, walls, roofs, shelves, trays, etc, is expedient.

Indirect methods (EN 12369 и ENV 1995-1) for approximate estimate of stiffness in bending of composite boards of type P6, based on the characteristic values of the modulus of elasticity in bending of those materials, are known. In specialised literature [1, 2, 3, 4 and 5], the matters related to the strain-strength characteristic of particleboards have been examined only in principle. At the same time, the stiffness St has been defined as a product of the inertia moment of their cross-section $J_y$ and the modulus of elasticity in bending $E_m$, i.e. $St = J_y \cdot E_m$ $N.mm^2$. Irrespective of the above, for the time being, standardised methods both with respect to the

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determination and with respect to the estimate of strain-strength index of SPBs are missing.

The essence of the method is the numerical and graphic determination of stiffness in bending of structural particleboards. The method is characterised by this that it is based on a summarised algorithm for stiffness St as a product of the algorithms for the maximum inertia moment max $J_y$ of the simulation modelled cross-section of the composite and an experimentally obtained mathematical expression of the dependence of the modulus of elasticity in bending $E_m$ on the bulk densities of the composite $\rho_b$ and the input wood raw material $\rho_{wo}$. The nomogram is a graphic expression of the numerical method for express determination of the stiffness St at set values of the input parameters thickness t and density $\rho_b$ of the composite board.

## THEORETICAL AND EXPERIMENTAL PREREQUISITES

The prerequisites on which the derivation of the summarised algorithm for numerical determination of stiffness is based consist in the following:

SPB is a technologically formed board-type wood-polymer composite with anisotropic structure, built of adhesively bonded lignocellulosic (wood) particles arranged in layers along its cross-section.

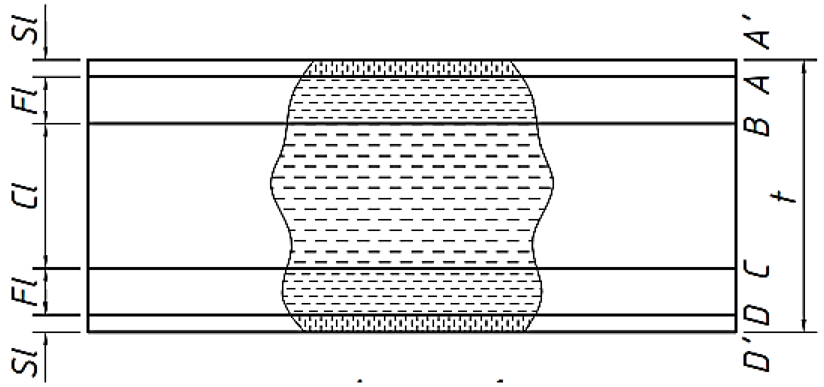


**Figure 1:**

A diagram of the modelled cross-section of the composite is presented in Fig. 1. The following layers are differentiated: two surface layers (SL) with a thickness below 0.5 mm, composed of powdery particles being of importance to give the necessary smoothness to the boards; two structural (face) layers (FL) with grain size distribution of 1.25 mm/0.50 mm, that are of great importance for the strain-strength stability in bending of the composite; core layer (CL) with grain size distribution of 2.50 mm/1.25 mm. At the same time, it is accepted in the world practice that the percentage of the structural layers in the total thickness of the board is from 30% to 40%, and the rational content of binder – respectively for face layers 10% to 13%, and in the core layer – 7% to 10%.

The stiffness in bending is one of the most important strain-strength characteristics of SPBs, that is determined both by their geometrical parameters thickness t and shape of their cross-section, forming the inertia moment $I_y$, and by their main physical parameter bulk density $\rho_b$, forming the strain-strength index – modulus of elasticity in bending $E_m = \varphi(\rho_b)$. The summarised algorithm for the stiffness St is the product mathematics expression:

$$St = J_y \,.\, E_m \text{ N.mm}^2 \quad \textbf{(1)}$$

The characteristic values for the stiffness refer to category of operating conditions and class of load duration from instantaneous to medium (EN 12369-1).

The macrostructure of the cross-section shape of SPBs may be presented, in terms of simulation, as a "double T beam" (Figures 2 and 3) with inertia moment

$$I_y = I_0 + t \cdot z\left(2z^2 - 3tz + t^2\right) \quad \textbf{(2)}$$

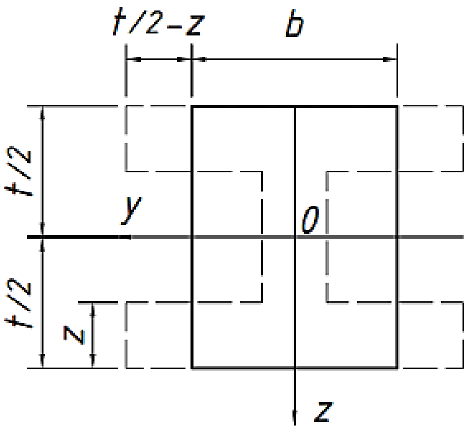


**Figure 2:**

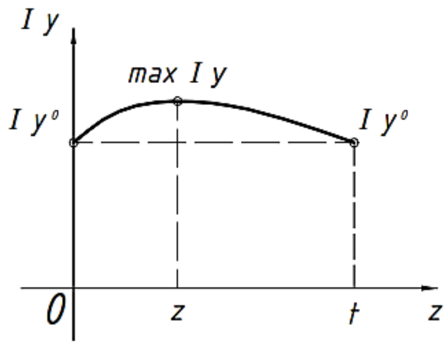


**Figure 3:**

The extremum of $J_y$ as a function of the parameter z that is part of the height (thickness t) $0 \le z \le t/2$ is obtained at

$$z = 1/2t\left(1 - \sqrt{3}/3\right) = 0.211\ \mathbf{t} \quad \textbf{(3)}$$

Then,

$$\max J_y = J_0 + 0.0962\ t^4\ \ mm^4 \quad \textbf{(4)}$$

Empirical equations of parabolic type for the bulk density depending on the manufacturing factors of composite boards have been established [1, 4] experimentally for the modulus of elasticity in bending. In doing so, it has been proven [3] that the bulk density of the boards $\rho_b$ is functionally dependent on the bulk densities of the input wood raw material $\rho_b = \varphi(\rho_{wo})$. To determine the numerical value of $E_m$, the empirical equation [5]

$$E_m = 4{,}7 \cdot 10^{-3} \cdot \rho_b^2 + 2{,}3\rho_b - 1{,}1\rho_{wo}\ \ N.mm^{-2} \quad \textbf{(5)}$$

has been worked out.

On the basis of the algorithms for determination of max $J_y$ and $E_m$, a summarised algorithm for determination of the numerical value for the stiffness in bending of SPBs

$$St = \max J_y \cdot E_m\ \ N.mm^2 \quad \textbf{(6)}$$

The algorithm for St is valid under following limiting conditions:

- to be in conformity with the standard requirements pursuant to EN 312 and EN 12369-1 for the admissible minimum values for the strength and modulus of elasticity in bending;
- to be in conformity with the proportional ratios for wooden beams, recommended in the specialised literature on "Strength of materials" (Toshev et al.)

$$\frac{1}{300} \le \frac{a}{\ell_1} \le \frac{1}{200}, \quad \textbf{(7)}$$

where $a$ is the maximum deflection and $\ell_1$ – the span.

In case of short concentrated load $\ell_1 = 20$ t and $a \leq 1$ mm,

$$\frac{1}{300} \leq \frac{1}{20t}, \text{ i.e. } t \geq 15 \text{ mm} \qquad \textbf{(8)}$$

Then, St ≥ 70 MN.mm$^2$.

In case of concentrated short load and standard size of test specimens, it is recommendable that the admissible minimum values for adm St to be:

$$\text{adm St} \geq 75 \text{ MN.mm}^2 \qquad \textbf{(9)}$$

It should be mentioned, that this method has an important practical purpose in the engineering solutions of different aspects of the applications of this composite material in building and furniture structures.

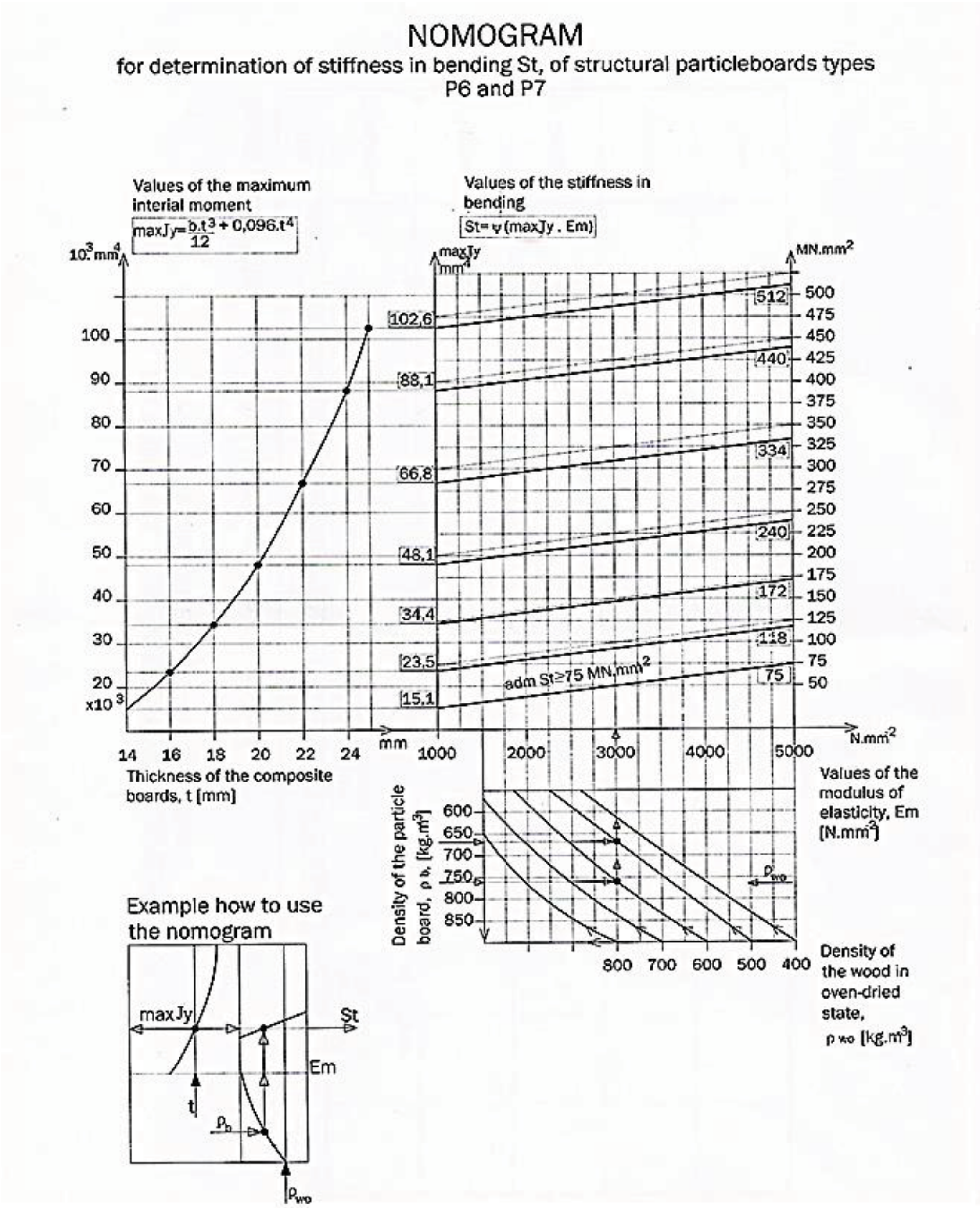


**Figure 4:**

For express graphic determination of the values of stiffness in bending of SPBs was drawed up correspondingly nomogram (Fig. 4), which consists essentially of three parts for: 1) a graphical determination of the maximum inertia moment max $J_y$ of the cross-section of the composite board; 2) a graphical determination of the modulus of elasticity $E_m$ of the composite boards; 3) a graphical determination of the stiffness in bending of the composite boards. The developed nomogram for determination of the stiffness in bending of SPBs is based on following principles:

The thickness of the composite board t in mm (see the diagram in the example) serves as a main input parameter for determination of the value of max $J_y$. The scale for the thickness t is 12 to 42, being graded for the standard thicknesses 13, 14, 16, 18, 20, 22, 24 and 25 mm. For the other input parameter for max $J_y$ – the width of test specimens b = 50 mm for concentrated bending load.

The maximum inertia moment max $J_y$ is determinating by equation (4).

The bulk density of the composite board $\rho_b$ in kg.m$^{-3}$ (see the diagram in the example) serves as a main input parameter for determination of the values of $E_m$. The scale for $\rho_b$ is 600 to 850 kg.m$^{-3}$ and is graded at intervals of 50 kg.m$^{-3}$. The other input parameter for $E_m$ – the bulk density of the input wood raw material in oven-dry state, is presented with the curves for $\rho_{wo}$ from 350 to 800 kg.m$^{-3}$ at intervals of 50 kg.m$^{-3}$.

The scale for $E_m$ is from 1500 to 5500 N.mm$^{-2}$ with an accuracy of 50 kg.m$^{-3}$. In conformity with the standard requirements (EN 312 and EN 12369-1), the working portion of the nomogram for $E_m$ may be limited from 2000 to 5000 N.mm$^{-2}$.

The values for the stiffness in bending of SPBs St vary from 50 to 550 MN.mm$^2$. For the structural boards with increased load-carrying capacity P6 at $E_m$ from 2000 to 5000 N.mm$^{-2}$ at short load, the values for the stiffness must be within the range above 75 MN.mm$^2$.

## 3. CONCLUSIONS

- It was developed an original method for numerical determination of stiffness in bending of structural particleboards, characterised by this that it is based on the product of the maximum inertia moment of simulation modelled cross-section of the composite as a “double T beam” and the algorithm of the experimentally established dependence of the modulus of elasticity in bending on the bulk densities of the composite and of the input wood raw material.
- It was draw up a nomogram for express graphic determination of the stiffness in bending of structural particleboards.

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