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THE INFLUENCE OF THE ANATOMY STRUCTURE UPON THE STACKING CAPACITY OF WOODEN BOXES

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Abstract: *Wooden boxes are products designed for storage and transport of various goods between the producer and the beneficiary, with or without intermediate storage. The functional characteristic of the wooden boxes is that of ensuring the protection and integrity of the products, both in storehouses and during the transport phases. The safe capacity depends mainly on the accurate sizing of the boxes with the type, size and weight of the loads and also of their correct stacking during storage.*
The sizing (or the dimensional checking by calculation) in the conditions of storage should take into account also the orientation of the anatomic structure against the forces subjected by the stack to the platform. According to this condition it can be said that the elements of the structure (lamellas, frameworks, frame stiles, etc.) are differently participated to the forces loading the vertical stack of wooden boxes.

Keywords: *wooden boxes, stacking, storage*

1. INTRODUCTION

The wooden boxes industrial processed have different orientations of the lamella grains in their constructive structure related by the position and sizes of the panels where they are included as components – top panel, side panel or end panel. Lamellas can be oriented along the length or width of the panels in the structure, contributing to a different design and in the same time to a different behavior as functional strength (handling) and stacking conditions.

The boxes with longitudinal elements (Fig.1.a) have the lamellas oriented along the length of the panels, taking into consideration that the dimensional relation between the interior sizes of the boxes is L>B>H and the boxes with transversal elements have the lamellas oriented along the width of the component panels of their structure (Fig.1.b.).

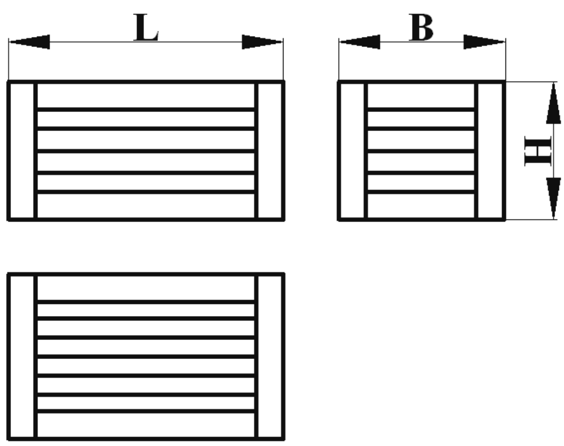

Fig.1.a. The longitudinal orientation of the lamellas in the panels of the box structure

Structures in which the lamellas are oriented both along the longitudinal and transversal direction are also possible (Fig.1.c.).

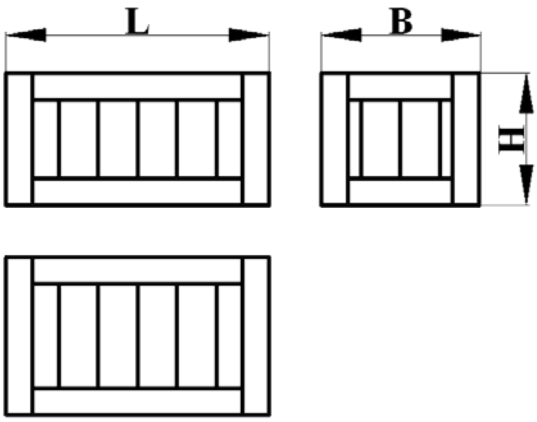

Fig.1.b. The transversal orientation of the lamellas in the panels of the box structure

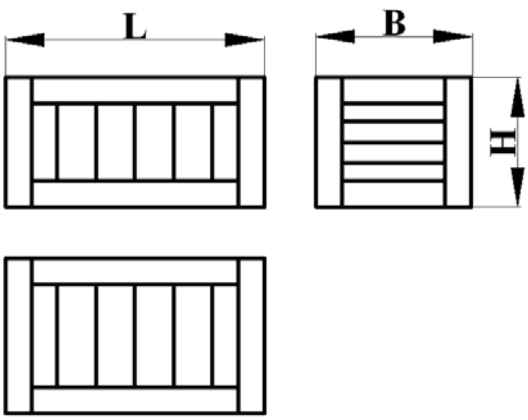

Fig.1.c. The longitudinal orientation of the lamellas on the end panel and the transversal orientation on the top, bottom and side panels of the wooden box

In order to calculate the sizes of the lamellas we have to consider the bending load of the panels in the conditions of the cargo weight. The lamellas resulted after calculation are characterized by the following:

- Lenght (l_0) depending on the type of the panel in the box structure and on its orientation;
- Width (b_0) depending on the dimensional ratio between the size of the panel and the size of lamellas (so to have an integer number of the identical lamellas);
- Thickness (g_0) depending on the size of the strains induced by the cargo load and the species of wood the lamellas are made of (the thickness is the result of bending strength calculation).

In case of wooden boxes with longitudinal orientation of the lamellas (Fig.1.a.), the results are as follows:

- for the top panel lamellas:

$$l_{0_1} = L;\ b_{0_1} = \frac{B}{n_1};\ g_{0_1} = g_{c_1}$$

- for the side panel lamellas:

$$l_{0_2} = L;\ b_{0_2} = \frac{H}{n_2};\ g_{0_2} = g_{c_2}$$

- for the end panel lamellas:

$$l_{0_3} = B;\ b_{0_3} = \frac{H}{n_3};\ g_{0_3} = g_{c_3}$$

where:
- n_1, n_2, n_3 – are the integer numbers of the lamellas for each panel;
- g_{c1}, g_{c2}, g_{c3} –are the thicknesses of lamellas resulted after calculation (in mm) and rounded up.

In case of wooden boxes with transversal orientation of the lamellas (Fig.1.b.), the results are as follows:

- for the top panel lamellas:

$$l_{0_1} = B;\ b_{0_1} = \frac{L}{n_1^{'}};\ g_{0_1} = g_{c_1}$$

- for the side panel lamellas:

$$l_{0_2} = H;\ b_{0_2} = \frac{B}{n_2^{'}};\ g_{0_2} = g_{c_2}$$

- for the end panel lamellas:

$$l_{0_3} = H;\ b_{0_3} = \frac{B}{n_3^{'}};\ g_{0_3} = g_{c_3}$$

where:
- $n_1^{'}$, $n_2^{'}$, $n_3^{'}$ şi g_{c1}, g_{c2}, g_{c3} have the same meaning as mentioned before.

In case of stacking for storing or transport purpose, the following issues are to be considered: the wooden boxes at the base of the stack are subjected to the maximum strains and the forces applied by the weight of the boxes (the load and their own weight) are subjecting only on the vertical elements.

2. STACKING – STRESSES AND WAYS OF DOWNLOADING

The general scheme of defining the level of stresses when stacking the wooden boxes is presented in figure 2, where Q is the total force that has to be takeover by the box situated at the bottom of the stack. If the boxes are considered to be identical, than Q is defined as (Cismaru&Fotin, 2010):

$$Q=(n-1)\cdot Q_l \qquad (1)$$

in which:

- Q_l is the load introduced in each box, defined as:

$$Q=Q_0+Q_M \qquad (2)$$

in which:

- Q_0 – is the own weight of the box;
- Q_M – represent the weight of the load in the box;
- n – is the number of the boxes stacked one top to the other, generally imposed by the ratio $\frac{H_s}{H}$, where H_s is the storing height (the height of the stack) and H is the box height.

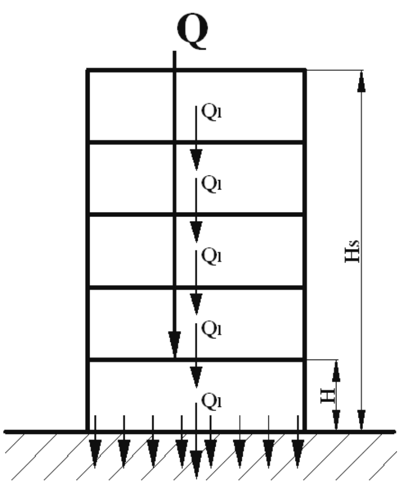

Fig.2. The scheme of the stack downloaded forces on the platform

The stresses that occur and develop in the vertical elements of the boxes (the stiles of the frame – when the lamellas are longitudinally orientated on the side panels and end panels or the stiles of the frame and the lamellas on the side panels and end panels in case of transversal orientation of the lamellas) (Fig.3) are combined stresses of compression and buckling.

The calculations have to take into account the fact that the box is functional and is safe for the integrity of the goods inside, as long as its shape remains unchanged (so no buckling for vertical elements) and that fact constitutes the input data for the proposed paper.

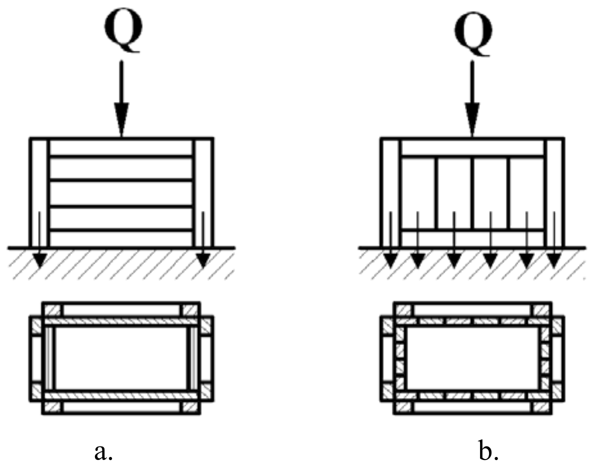

Fig.3. The downloaded stacking forces on the platform
a. at the wooden boxes with longitudinal elements
b. at the wooden boxes with transversal elements

2.1. Elements for a comparative study. In case of calculation the parallel compression along the wood grains (calculation applied to vertical elements) the relationship of defining the maximum force applied until buckling the structural element will be considered. The general calculation scheme is shown in Fig.4.

In this case the next equation is used:

$$Q_{\max}=b\cdot\delta\cdot\varphi\cdot\sigma_{c_{II}} \qquad (4)$$

in which:

- $\sigma_{c_{II}}$ is the admitted strain to the parallel compression along the grains (depending on the species of wood), in N/m^2;

- b and δ are the sizes of the crosscut section of the vertical element, in m;

- φ is the coefficient of reducing the compression strain depending on the suppleness coefficient of the vertical element.

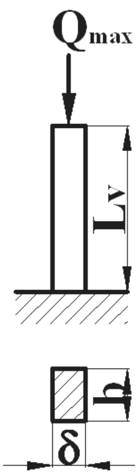

Fig.4. General calculation scheme

The φ coefficient has a complex action according to the suppleness coefficient λ, as resulted from table 1.

Table 1

The values of φ coefficient against λ (Cotta, 1983)

φ	**10**	**30**	**50**	**80**	**100**
λ	0,99	0,93	0,80	0,48	0,31
φ	**130**	**150**	**180**	**200**	
λ	0,18	0,14	0,1	0,08	

The calculation of the suppleness coefficient is made using the equation:

$$\lambda = \mu \cdot \frac{L_v}{i} \qquad (5)$$

where:

- L_v is the length of the element, [m]

- μ is the stiffness coefficient (due to the rigid fixing in the structure), having the following values:

μ=0,5 for rigid joints of the elements;

μ=0,75 for half-rigid joints with nails of the elements;

μ=1, for the mobile joints.

- i, is the radius of inertia of the crosscut section, calculated with the next equation:

$$i = \sqrt{\frac{I}{S}}\ [\mathrm{m}] \qquad (6)$$

in which:

- I – is the moment of inertia calculated with the equation: $I = \frac{b \cdot \delta^3}{12}, [m^4]$, depending of the sizes of the crosscut section;

- S – is the crosscut section of the vertical element calculated with equation: $S = b \cdot \delta, [m^2]$.

The value of the radius of inertia of the vertical elements resulted after substituting is as follows:

$$i = \sqrt{\frac{b \cdot \delta^3}{12 \cdot b \cdot \delta}} = 0{,}289\delta, [m]$$

When taking into account the submitted data and the data shown in figures 3 and 5, than the maximum force taken over by the box, without buckling ([Curtu & Ghelmeziu, , 1984), at the basis of the stack will be differently determined, as follows:

- for the boxes with longitudinal lamellas on the side panels and end panels:

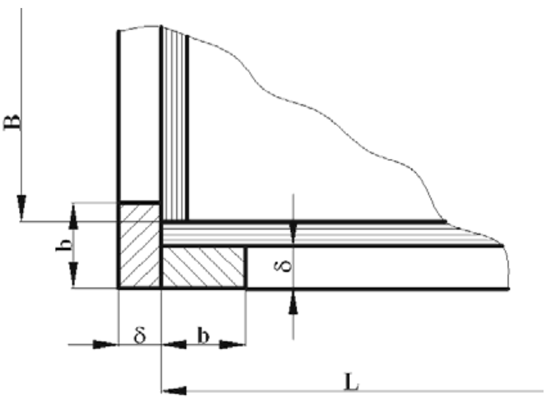

Fig.5a. Elements that download the stacking forces. Boxes with longitudinal lamellas on side panels and end panels

$$Q_{\max_1} = n_0 \cdot b \cdot \delta \cdot \varphi_0 \cdot \sigma_{cII}, \text{[N]}, \quad (7)$$

in which:

- n_0, is the number of stiles of the frames of the side and end panels – depending on the constructive solution of the box (4, 6, 8 pcs).

- φ_0 – is the specific coefficient to the sizes of the stile crosscut section.

- for boxes with transversal lamellas on the side panels and end panels:

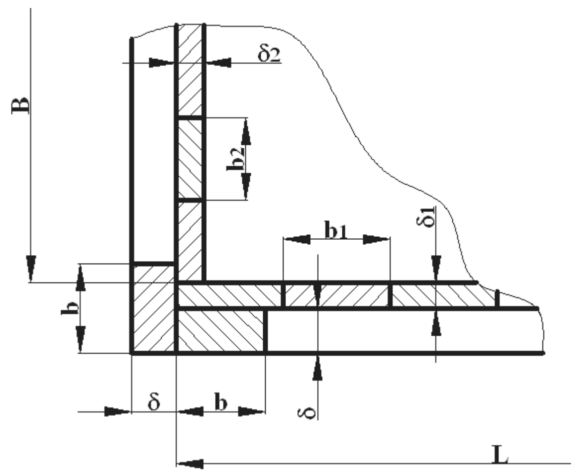

Fig.5b. Elements that download the stacking forces. Boxes with transversal lamellas on side panels and end panels

$$Q_{\max_2} = n_0 \cdot b \cdot \delta \cdot \varphi_0 \cdot \sigma_{cII} + n_1 \cdot b_1 \cdot \delta_1 \cdot \varphi_1 \cdot \sigma_{cII} + n_2 \cdot b_2 \cdot \delta_2 \cdot \varphi_2 \cdot \sigma_{cII}, \text{[N]}, \quad (8)$$

in which:

- n_0 and φ_0, are described above
- n_1, b_1, δ_1, φ_1- are elements specific to the lamellas of the side walls, where $n_1 = \frac{2L}{b_1}$ and φ_1, calculated depending on the lamellas section (b_1, δ_1), n_1 being an even number;
- n_2, b_2, δ_2, φ_2- are elements specific to the lamellas of the end panels of the box, in which $n_2 = \frac{2B}{b_2}$ and φ_2 is calculated depending on the lamellas section (b_2, δ_2), n_2 being an even number.

Analyzing equations (7) and (8), it can be said that the boxes with transversal elements can download a higher stacking load.

The ratio:

$$\frac{Q_{\max_2}}{Q_{\max_1}} \cdot 100 = c \;, \quad [\%] \qquad (9)$$

- is the coefficient of the percentage increasing of the capacity of downloading the stacking forces, in case of boxes with transversal lamellas (on side panels and end panels) against the case of the boxes with longitudinal lamellas.

If the strength condition is imposed:

$$Q_{\max_1} \le (n-1) \cdot Q_l \qquad (10)$$

- for the wooden boxes with longitudinal elements

$$Q_{\max_2} \le (n-1) \cdot Q_l \qquad (11)$$

- for the wooden boxes with transversal elements

It can be said that the limits of equations (10) and (11) may be used for sizing the stiles of the resistance frames (from the structure of the panels), knowing that the sizes of the lamellas resulted from the bending strength condition.

3. CONCLUSIONS & ACKNOWLEDGMENT

The use of wooden boxes with transversal lamellas of the panels (top, side, end panels) related to panel's sizes bring some advantages, as:

- allow the use of small sized wood, as long as the relation between the interior sizes of the box is L>B>H;
- ensure a smaller amount of wood to be used, the required thicknesses of the transversal lamellas being smaller than that of the longitudinal ones;
- the stacking capacity is higher in case of transversal lamellas, these ones downloading higher weights on the

- platform by the vertically oriented lamellas;
- boxes weight - for the same load it is smaller for transversal elements, increasing the stacking capacity.

In order to have benefit of the advantages presented in the present, the sizing of the boxes (depending on the orientation of the structural elements – the lamellas) must be fully achieved, in terms of:

- bending strength – for the thickness value and then the width is calculated depending on the ratio between the interior dimensions of the boxes and the widths of the lamellas, so to obtain integer numbers for each panel;
- combined compression with buckling - when the dimensions of the stiles of the frames are obtained, the frames being used in the structure of the panels and to consolidate the structures.

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