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МЕТОД РАСЧЕТА ДЕФОРМАЦИИ УПРУГИХ ЭЛЕМЕНТОВ НЕСУЩИХ КОНСТРУКЦИЙ

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В работе получены аналитические выражения прогибов закрепленной с двух концов упругой пластины под действием сжимающих усилий. Получены формулы для расчета деформации и показано, что максимальная величина стрелы поперечного прогиба зависит от величины сжимающего усилия и изгибной жесткости пластины. Приведен пример расчета максимального прогиба по полученной формуле на реальных данных и сделано сравнение с экспериментальными результатами, что дает возможность сделать вывод о высокой точности расчетов по полученной формуле при соблюдении допустимых значений параметров.
Ключевые слова: деформация пластины, сжимающие усилия, поперечный прогиб

Analytical expressions are obtained for the deflections of the elastic plate fixed at two ends under the action of compressive forces. Formulas for calculating the deformation are obtained and it is shown that the maximum value of the transverse deflection boom depends on the width, thickness and length of the plate, the amount of compressive force and the bending stiffness of the plate. An example of calculating the maximum deflection according to the obtained formula on real data is given and a comparison with experimental results is made, which makes it possible to conclude that the calculations using the obtained formula are highly accurate while observing the permissible values of the parameters.
Keywords: plate deformation, compressive forces, lateral deflection

Introduction

When designing engineering structures, they usually achieve three basic conditions: strength, rigidity and structural stability.It is known that elements such as cylindrical rods or thin platescan be deformed under the action of external forces and, at certain critical loads, their shape becomes unstable: cylindrical rods are bent, and the plates swell.Theoretical studies in this direction were carried out at the beginning of the last century, in particular, S.P. Timoshenko [1,2].However, many questions related to obtaining calculation formulas that are in good agreement with experimental data remain open.

In this paper, we consider the problem of obtaining an analytical dependence of the deflection of a plate fixed at two ends from its geometric and physical characteristics when it is compressed in the longitudinal direction.

Mathematic model

Consider a plate or a piece of flexible tape of length L_n, width b ($b < L_n$), and thickness δ, $\delta << b$. The compression of the segment in the longitudinal direction is performed by the force N distributed along the end face (Fig. 1). It is necessary to find the value of N, the arrow of the longitudinal deflection h_0, the radius of curvature of the longitudinal deflection ρ_0, at which the arrow of the transverse deflection Δh_0 has a maximum value.

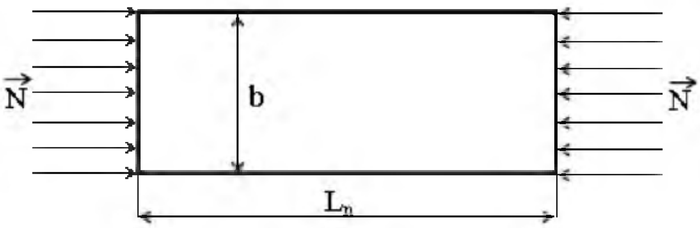

Figure. *1* –Undeformed plate state. b, L_n – width and length plate

The differential equation of the longitudinal deflection of the deformed plate has the form

$$\frac{\partial^4 W}{\partial x^4} + 2\frac{\partial^4 W}{\partial x^4 \partial y^4} + \frac{\partial^4 W}{\partial y^4} + \frac{N}{Db}\frac{\partial^2 W}{\partial x^2} = 0, \qquad (1)$$

where D – bending stiffness, calculated by the formula:

$$D = \frac{E\delta^2}{12(1-\mu)^2}, \qquad (2)$$

here E is the elastic modulus.

Boundary conditions for a given fixing method:

$$x = 0,\ W=0,\ z_1 = D\left(\frac{\partial^2 W}{\partial x^2} + \mu\frac{\partial^2 W}{\partial y^2}\right) = 0,$$

$$x = L_n,\ W=0,\ z_2 = -D\left(\frac{\partial^2 W}{\partial x^2} + \mu\frac{\partial^2 W}{\partial y^2}\right) = 0.$$

Conditions at the free edges of the plate at y = ± b/2:

$$\begin{cases} z_2 = D\left(\frac{\partial^2 W}{\partial x^2} + \mu\frac{\partial^2 W}{\partial y^2}\right) = 0, \\ \frac{\partial z_2}{\partial y} + 2\frac{\partial H}{\partial x} = 0, \end{cases}$$

where $H = D(1-\mu)\frac{\partial^2 W}{\partial x \partial y}$.

The solution to equation (1) under conditions (2) is sought in the form

$$W = f(y) \cdot \sin\frac{m\pi x}{L_n}.$$

Then for the function f(y) we have the equation:

$$f^{(IV)}(y) - 2\left(\frac{m\pi}{L_n}\right)^2 f''(y) + \left[\left(\frac{m\pi}{L_n}\right)^4 - \frac{N}{Db}\left(\frac{m\pi}{L_n}\right)^2\right] f(y) = 0, \qquad (3)$$

under boundary conditions:

$$f''(y) - 2\left(\frac{m\pi}{L_n}\right)^2 f(y) = 0\Big|_{y=\pm\frac{b}{2}}, \quad f'''(y) - (2-\mu)\left(\frac{m\pi}{L_n}\right)^2 f'(y) = 0\Big|_{y=\pm\frac{b}{2}}. \qquad (4)$$

As shown in the work [4], a necessary condition for the existence of a solution (3)-(4) is the equality

$$\frac{\alpha^2 - \frac{\mu m^2 n^2}{L_n^2}}{\beta^2 - \frac{\mu m^2 n^2}{L_n^2}} = \frac{\alpha \cdot th(\alpha b/2)}{\beta \cdot th(\beta b/2)}, \qquad (5)$$

where $\alpha = \sqrt{\sqrt{\frac{N}{Db}\left(\frac{m\pi}{L_n}\right)^2} + \left(\frac{m\pi}{L_n}\right)^2}$, $\beta = \sqrt{\sqrt{\frac{N}{Db}\left(\frac{m\pi}{L_n}\right)^2} - \left(\frac{m\pi}{L_n}\right)^2}$.

Let's denote

$$Z(\alpha,\beta) = \frac{\alpha^2 - \frac{\mu m^2 n^2}{L_n^2}}{\beta^2 - \frac{\mu m^2 n^2}{L_n^2}} \cdot \frac{ch(\alpha b/2)}{ch(\beta b/2)} \cdot ch(\beta y),$$

then the solution to problem (3)-(4) can be written as

$$f(y) = 2 \cdot \left[ch(\alpha y) - Z(\alpha,\beta)\right], \qquad (6)$$

Finally, for the deflection function W (x, y), we obtain the expression:

$$W(x,y)=2\sin\frac{m\pi x}{L_n}\cdot\left[ch(\alpha y)-Z(\alpha,\beta)\right]. \tag{7}$$

We set m = 1 and introduce the notation:

$$u=\frac{Nb}{D},\quad v=\frac{\pi^2 b^2}{L_n^2}, \tag{8}$$

then

$$\alpha=\frac{\sqrt{v+\sqrt{uv}}}{b},\quad \beta=\frac{\sqrt{v-\sqrt{uv}}}{b}.$$

The ratio (5) in the new notation will take the form:

$$\left[\frac{(1-\mu)v+\sqrt{uv}}{(1-\mu)v-\sqrt{uv}}\right]^2=\frac{\sqrt{v+\sqrt{uv}}}{\sqrt{v-\sqrt{uv}}}\cdot\frac{th\frac{\sqrt{v+\sqrt{uv}}}{2}}{th\frac{\sqrt{v-\sqrt{uv}}}{2}}. \tag{9}$$

Since the value of v is always known, from this relation we can find the value of u. From (7), after replacing α and β with u, v, we can determine the deflection at any point in a segment of a flexible tape:

$$W(x,y)=2\sin\frac{m\pi x}{L_n}\left[ch(\frac{\sqrt{v+\sqrt{uv}}}{b}y)-\frac{(1-\mu)v+\sqrt{uv}}{(1-\mu)v-\sqrt{uv}}\frac{ch(\frac{\sqrt{v+\sqrt{uv}}}{2})}{ch(\frac{\sqrt{v-\sqrt{uv}}}{2})}ch(\frac{\sqrt{v-\sqrt{uv}}}{b}y)\right]$$

In the middle of the passage with x = Ln/2, y=0, we find the quantity h_0:

$$h_0=2\left[1-\frac{(1-\mu)v+\sqrt{uv}}{(1-\mu)v-\sqrt{uv}}\frac{ch(\frac{\sqrt{v+\sqrt{uv}}}{2})}{ch(\frac{\sqrt{v-\sqrt{uv}}}{2})}\right]. \tag{10}$$

The sought quantities ρ_0 and N are equal, respectively: $\rho_0=\frac{b^2}{uh_0}$, $N=\frac{uD}{b}$. (11)

The maximum value of the arrow of the transverse (along the y axis) deflection is determined as the difference:

$$\Delta h_{max}=W(\frac{L_n}{2},\frac{b}{2})-W(\frac{L_n}{2},0). \tag{12}$$

So, the whole difficulty of solving the formulated problem lies in finding u from equation (9). This equation for u can be solved by the method of successive approximations, taking for the zeroth approximation the value

$$u_0=(1-\mu)\cdot v\cdot[1+\frac{6\mu}{6-\mu v}].$$

Let us evaluate the effect of the load on the deformation of a rectangular plate.

The geometric characteristics of a plate under the action of longitudinal compressive forces N (Fig.1) are reduced to two dimensionless parameters u and v. The quantity v is given, and u is determined from the transcendental equation (9).

After simple transformations we get:

$$u=\begin{cases}(1-\mu)v[1+6\mu/(6-\mu v)], & \text{if } 0<v\le 0.2;\\ 1.0225v-0.0263, & \text{if } 0.2<v\le 1;\\ 0.99, & \text{if } v>1.\end{cases}$$

Considering that in practice the value of v is in the range 0 <v ≤ 0.2, for the desired parameters h_0 and ρ_0 we obtain the expressions:

$h_0 \approx 3.34v + 13.34$, $\rho_0 \approx b^2/(uh_0)$.

Results

As an example of the application of the above methodology, in Table 1 compares the experimental data with the calculation results for the case L_n = 1270 mm, b=215 mm, μ=0,3.

The dependence of the maximum deflection h_0 on the parameter ν is close to linear, as can be seen from Fig. 2.

Table 1 – Comparison of results calculations with experiment

parameter	calculations	experiment
h_0	147,6	146,0
ρ_0	1252	1300
N	9,4 kG	10 kG
Δh_{max}	0,122 mm	0,125 mm

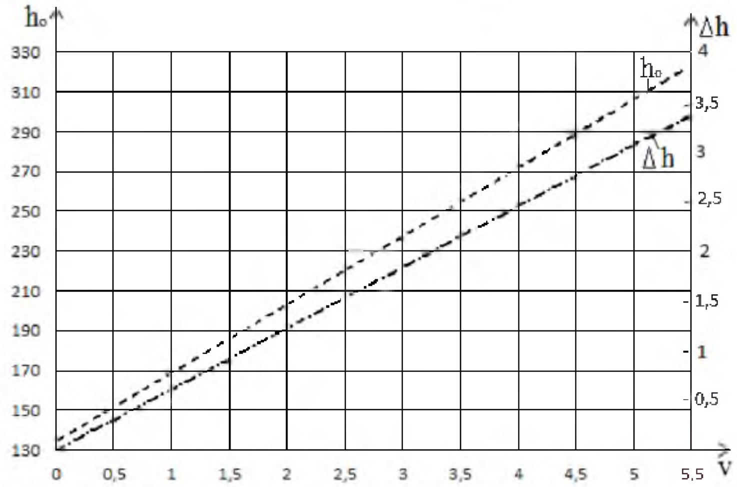

Figure*2* – The dependence of the transverse deflection on parameter ν

Conclusion

Based on the data presented, it can be concluded that the accuracy of the calculations using the formulas obtained is sufficient for practice, subject to the permissible values of the parameters.

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АКТУАЛЬНОСТЬ ПРОБЛЕМЫ ИСПОЛЬЗОВАНИЯ ГАЗА В КАЧЕСТВЕ СУДОВОГО ТОПЛИВА

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Статья посвящена двум системам подвода газа к судовым малооборотным дизелям типа SME-GI, одна из которых предусматривает забор газа из отдельного танка, а другая из паровой линии грузовой системы поршневым компрессором. Анализируется структура систем, преимущества каждой из них и суда, на которых они используются.

Ключевые слова: дизель, газ, топливная система, эмиссионный контроль, безопасность.

The article is devoted to two systems for supplying gas to low-speed marine diesel engines of the SME-GI type, one of which provides for gas intake from a separate tank, and the other from the steam line of the cargo system with a piston compressor. The structure of the systems, the advantages of each of them and the vessels on which they are used are analyzed.

Key words*:* diesel, gas, fuel system, emission control, safety.