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Stability of Elongated Plates Reinforced along the Contour with Thin-Walled Rods

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ABSTRACT: In this article, free oscillation of the plate is considered when the sides of $x = 0$, a are hinged and other sides of $y = \pm b/2$ are free. Free sides connected with thin, open profile rods.

KEYWORDS. Compressed, stretched, stability, elongated, plates, elastic pinching, articulated, twisted, bending, reinforced, unsupported, edge, stiffness.

I. PROBLEM STATEMENT AND LITERATURE REVIEW.

It is known that taking into account constrained torsion in thin-walled rods of an open profile makes it possible to more fully identify reserves for increasing the torsional rigidity of such rods. Therefore, the influence of constrained torsion affects an increase in the degree of pinching of the edges of the plate, when thin-walled rods of an open profile are taken as reinforcing elements.

In the literature [2, 3, 4, 6], the following method of drawing up boundary conditions along the contact line of the plate with the reinforcing ribs is described. The loads transmitted by the plate to the ribs (rods) are considered equal, but reversed in the direction of the forces in the corresponding sections of the plate. Then kinematic conditions of equality of displacements at the points of contact of the reinforcing rods with the plate are introduced into these force conditions.

In publications [1, 5], a method for drawing up refined boundary conditions on the interface line of the plate with the rod is proposed, which allows taking into account the constraint of the deplaning of the end sections of the ribs. At the same time , the degree of constraint of the deportation is taken into account by some parameter d_k .

II. THE SOLUTION METHOD.

As far as we know, a closed solution to the problem of stability of elongated rectangular plates can be obtained in single trigonometric series only when two parallel edges are pivotally supported, while the other two edges can be fixed arbitrarily (M.Levy's solution).

In many cases, it is of practical interest to study the problem of stability of elongated plates $(a > b)$.

Consider the problem of stability of elongated plates, the long edges are supported by thin-walled rods, and the short ones are supported pivotally. Such a case corresponds, for example, to a separate compartment of the ship's

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ceiling with a longitudinal set or compressed thin-walled elements of some building structures (Fig.1).

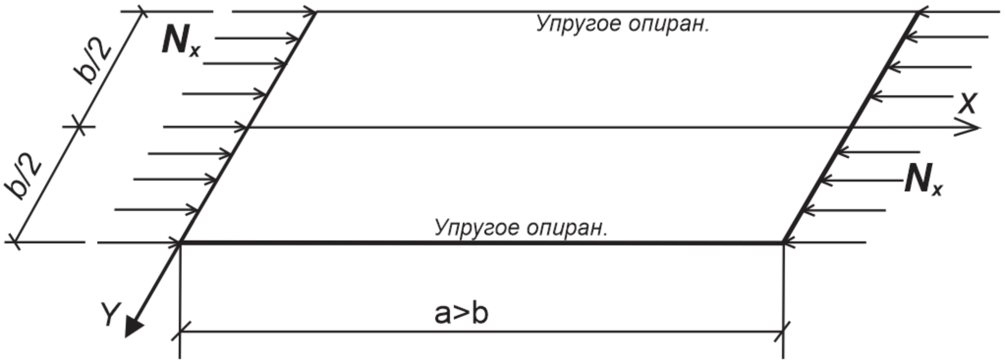

Fig.1. The plate, the long edges are supported by thin-walled rods, and the short ones are supported pivotally.

A uniformly distributed intensity load is applied to the pivotally fixed edges (at the level of the median plane). $N_x = \sigma\delta = const$, *where* $\delta -$ plate thickness.
Let 's write down the known differential equation of the problem

$$D\nabla^2\nabla^2 w + N_x \frac{\partial^2 w}{\partial x^2} = 0, \quad D = \frac{E\delta^3}{12(1-\mu^2)}\ , \tag{1}$$

the solution of which we will present in the traditional form

$$w(x,y) = \sum_{n=1.2}^{\infty} f_n(y) \sin \lambda_n x, \quad \lambda_n = \frac{n\pi}{a}, \tag{2}$$

satisfying the boundary conditions of the hinge support on the edges $x = 0, a$ [2, 3, 4, 6].

Substituting (2) into (1) we obtain the equation for determining the desired function $f_n(y)$

$$f_n^{IV} - 2\lambda_n^2 f_n^{II} + \lambda_n^2\left(\lambda_n^2 - \frac{N_x}{D}\right) f_n = 0 \tag{3}$$

The solution of equation (3) depends on the type of roots of the characteristic equation

$$S_{1,2} = \pm\sqrt{\lambda_n\left(\lambda_n + \sqrt{\frac{N_x}{D}}\right)},\ S_{3,4} = \pm\sqrt{\lambda_n\left(\lambda_n - \sqrt{\frac{N_x}{D}}\right)}. \tag{4}$$

It is known that in a plate pivotally supported at all edges, the critical value of the load intensity under one-sided compression is equal to (see for example [3])

$$N_x^* = K\pi^2\frac{D}{b^2}, \quad K = \left(\frac{\pi b}{a} + \frac{a}{\pi b}\right)^2 \tag{5}$$

It follows from (5) that at any degree of elastic fixation (except when the longitudinal edges are free from support) $N_x^* > \lambda_n^2 D$ for arbitrary values $\frac{a}{b}$ и n. Therefore, in (4) the roots $S_{1,2}$ are always real, and the roots $S_{3,4}$ imaginary.

With this in mind, we present the solution of equation (3) in the form

$$f_n = C_1 ch\alpha_n y + C_2 sh\alpha_n y + C_3 \cos\beta_n y + C_4 \sin\beta_n y \tag{6}$$

where

$$\alpha_n = \sqrt{\lambda_n\left(\sqrt{\frac{N_x}{D}} + \lambda_n\right)}, \quad \beta_n = \sqrt{\lambda_n\left(\sqrt{\frac{N_x}{D}} - \lambda_n\right)}, \tag{7}$$

To concretize further calculations, we introduce some particular simplifying assumptions. First, to simplify the calculation, we will assume that the reinforcing rods and the conditions for fixing their ends on both edges of the plate are the same. This circumstance will make it possible to use the symmetry of the curvature of the plate relative to the x axis and put the constants in (6)

$C_2 = C_4 = 0.$

Let us now subordinate the function $f_n(y)$ to the boundary conditions [1, 5]

Conditions for elastic support at the edges $y = \pm\frac{b}{2}$:

$$f_n = \frac{f_n^{III} - (2-\mu)\lambda_n^2 f_n^I}{t_u b \lambda_n^4}, \tag{8}$$

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where $t_u = \frac{C_u}{d_u(1+\lambda_n^2 \frac{k_\varphi}{k_2^2})}$, $C_u = \frac{EJ_y}{Db}$, $k_2^2 = \frac{GF}{EJ_y}$, (9)

$$d_u = 1 \text{ при } \frac{d^2 w_{п.с.}}{dx^2}\Big|_{x=0,a}, = 0, \quad (10)$$

$$d_u = 1 - \frac{16+8(-1)^n}{n^2\pi^2} \text{ by } \frac{dw_{п.с.}}{dx}\Big|_{x=0,a} = 0\,. \quad (10a)$$

Recall that the coefficient $k_ф$ included in (12), depends on the shape of the cross-section: for example, for a rectangle $k_ф = 1{,}2$, for I-beams of rolling assortment ГОСТ 8239-56 $k_ф \approx (2{,}0 \div 2{,}4)$

We now subordinate function (6) to the boundary conditions (8). As a result, we come to the following system of two homogeneous equations with respect to constants C_1 and C_3:

$$C_1\{t_u\psi^4 \text{ch}\xi - 2[4\xi^2 - (2-\mu)\psi^2]\xi sh\xi\} +$$
$$+C_3\{t_u\psi^4 cos\eta - 2[4\eta^2 + (2-\mu)\psi^2]\eta sin\eta\} = 0 \quad (11)$$

In (11) it is denoted $\xi = \frac{\alpha_n b}{2}$, $\eta = \frac{\beta_n b}{2}$, $\psi = \lambda_n b$ (12)

Since the trivial solution of the system (11) $C_1 = C_3 = 0$ if it is not of interest, then in order to obtain the stability equation, it is necessary to equate the determinant of this system to zero. As a result of the disclosure of the determinant, we get:

$$(4\xi^2 - \mu\psi^2)[4\eta^2 + (2-\mu)\psi^2]\eta sin\eta +$$
$$+(4\eta^2 + \mu\psi^2)[4\xi^2 - (2-\mu)\psi^2]\xi th\xi cos\eta - \quad (13)$$
$$-2t_u\psi^4(\xi^2 + \eta^2)cos\eta = 0.$$

The relationship between ξ и η, and also the formula for the critical intensity of the load N_x^* stem from (7)

$$\xi^2 - \eta^2 = \frac{\psi^2}{2}, \qquad N_x^* = 4D\frac{(\xi^2+\eta^2)^2}{(\psi b)^2}. \quad (14)$$

The joint solution of the last equation with (131) leads to the determination of the entire spectrum of critical values N_x^*.

Minimum value N_x^* with the specified parameters t_u, $\frac{a}{b}$ corresponds to certain values n.

Figure 2 shows a graph of the dependence $\frac{N_x^*}{N_э}$ от $\frac{a}{b}$, built for different values C_u. For all curves it is accepted $ka = \infty$, т.е. the shear deformation during bending of the reinforcing rods is neglected. The upper and lower curves in Fig. 2 refer to two extreme cases: $C_u = \infty$ (the plate is pivotally supported on rigid supports along all edges), $C_u = 0$ (the long edges of the plate are free from support, i.e. there is a beam scheme). The intermediate curves correspond to the range $0 < C_u < \infty$, moreover, the dashed lines refer to the case of hinge fastening of the ends of the reinforcing rods, and the solid lines refer to the case of rigid sealing.

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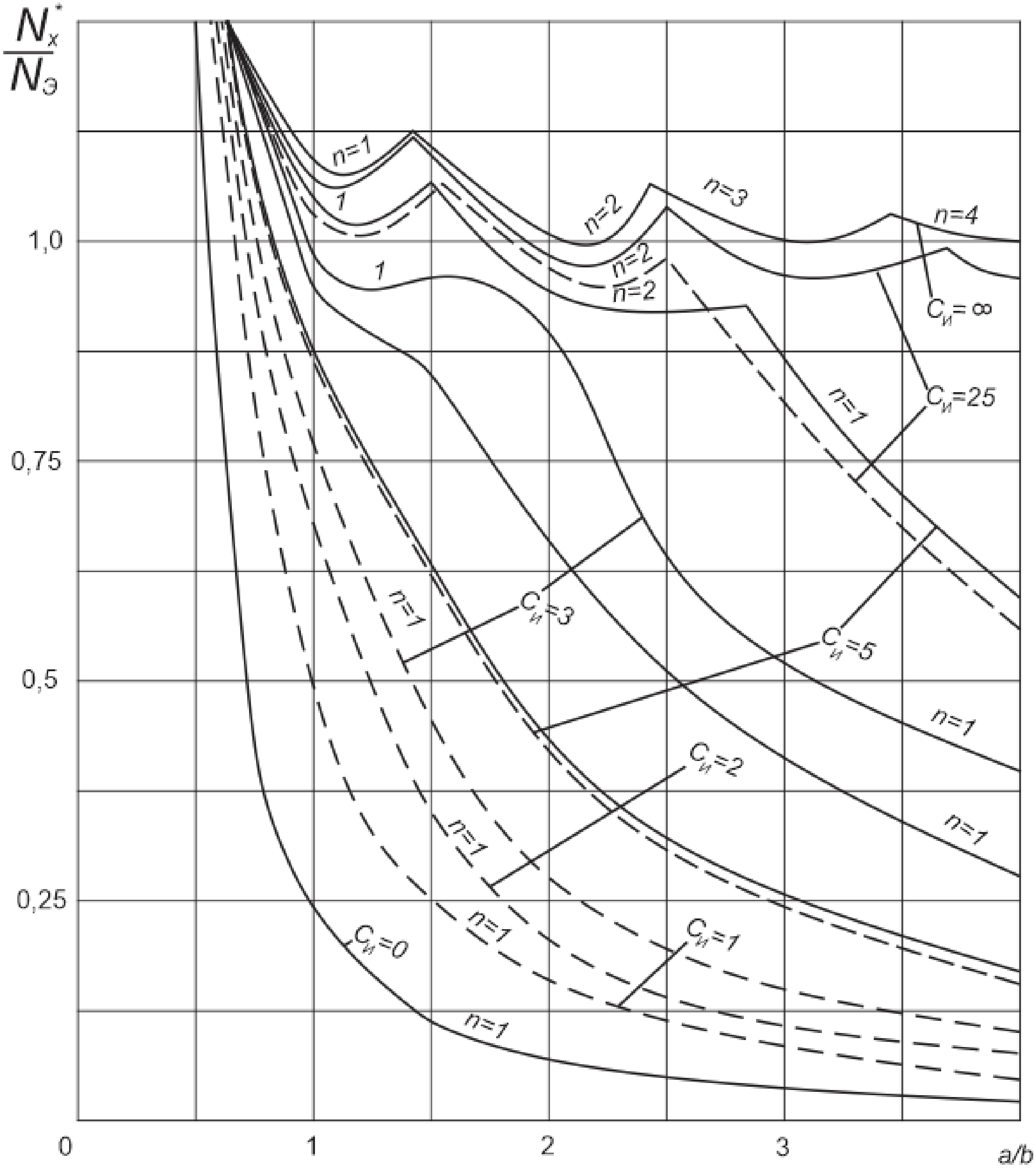

Fig.2. Dependency graph $\frac{N_x^*}{N_э}$ от $\frac{a}{b}$, built for different values C_u.

From Fig. 2 it can be seen how strongly the method of fixing the ends of the reinforcing rods affects the stability of the plate. This influence affects not only quantitatively, but also qualitatively. So, for example, when $C_u = 25$ and $\frac{a}{b} \geq 3 \div 4$ the same reinforcing rod (but with different conditions for fixing its ends) leads to a loss of stability of the plate by a different number of half-waves.

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III. CONCLUSION

It is known that with the cross-sectional dimensions of thin-walled rods supporting the long sides of the plate unchanged, the degree of elastic pinching during longitudinal compression of the plate increases with an increase in the ratio of the dimensions of its sides $\frac{a}{b}$ $(a > b)$. For extremely long plates when $a > (6-8)b$ the degree of pinching is close enough to a hard seal.

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