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FLOW CONDITIONS FOR COATING SHELLS AND CALCULATIONS OF CARRYING CAPACITY

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ABSTRACT

The article discusses the procedure for calculating the bearing capacity of rigid plastic shells based on linearly programmed methods. For this reason, it becomes necessary, instead of the curvilinear flow conditions of coating shells, to obtain their linear approximations of bodies bounded by sections of hyper planes.

KEYWORDS: *Coating Shells, Hyper surface, Coating Shell, Hypersurface, Fluidity, Tension, Compression, Bending, Equilibrium.*

INTRODUCTION

The static and kinematic formulation of the limiting equilibrium problems for the shells of the coatings shows that the yield condition plays an important role in determining the upper and lower bounds for the limiting load.

In the general case, eight internal forces act at each point of the shell: normal forces N_x ^ and N_y ^, shear forces N_xy ^, transverse forces Q_x ^ and Q_y ^, bending moments M_x ^ and M_y ^, and torques M_xy ^. transverse forces on the transition of the material to the plastic state are small, therefore often the plasticity condition connects only six of the eight listed forces and has the form [1]:

$$F_1 \ (N_x , N_y , N_{xy}, M_x , M_y , M_{xy}.) \leq K_1 \qquad (1)$$

Where k_1 ^ is a constant that depends on the flow rate of the material under simple tension (compression).

Equation (1) in the space of internal efforts N_x ^, N_y ^, N_xy ^… .M_xy ^. describes a closed convex hyper surface surrounding the origin. There are various kinds of specific conditions of yield (1) and variables N_x ^, N_y ^, N_xy ^, M_x ^, M_y ^, M_xy ^. are included in them, as a rule, in the second degree. The type of F_1 ^ depends on the properties of the material, on the shape of the shell and other factors. An essential feature of the yield conditions (1) is that the function F_1 ^ connects all six force factors.

In addition to the yield conditions of the type (1) and the theory of the limiting equilibrium of shells, such conditions have become widespread which relate only a part of the variables to each other, for example, [1]:

$$\begin{cases} F_2 \left(\mathrm{N}_x, \mathrm{N}_y, \mathrm{N}_{xy},\right) \leq K_2 ; \\ F_3 \left(\mathrm{M}_x, \mathrm{M}_y, \mathrm{M}_{xy}.\right) \leq K_3 . \end{cases} \quad (2)$$

Or

$$\begin{cases} F_4 \left(\mathrm{N}_x, \mathrm{N}_y, \mathrm{N}_{xy},\right) \leq K_4 \\ F_5 \left(\mathrm{M}_x, \mathrm{M}_y, \mathrm{M}_{xy}.\right) \leq K_5 \\ F_6 \left(\mathrm{N}_{xy}, \mathrm{M}_{xy}.\right) \leq K_6 \end{cases} \quad (3)$$

Here K_1 ^, K_2 ^, ⋯, K_6 ^ -constants.

From (2) and (3) it can be seen that instead of one condition (1) we obtain two or three conditions. In (2), only bending forces enter into two equations, respectively, and three equations (3) combine internal forces of the same directions. Instead of the regular "smooth" hypersurface (1), we now obtain the yield condition in the form of the intersection of two or three hyper surfaces. This condition is singular; it has edges and vertices.

Yield conditions of the type (2) or (3) are called “with partial interaction” yield conditions, in contrast to condition (1) with full interaction of all internal force factors.

Moving along the path (1) → (3), one can obtain a condition of the form

$$\mathrm{N}_x \leq K_1 , \mathrm{N}_y \leq K_8 , \cdots, \mathrm{M}_{xy} \leq K_{12} \quad (4)$$

Assuming complete independence between the force factors in the limiting state. In the six-dimensional space of internal forces, condition (4) is met by a hyperparallelopiped.

The modern theory of the limiting equilibrium of shells allows the researcher to choose the yield condition in the finished form. Another possibility is to obtain this condition in the space of internal forces N_x ^, ⋯, M_xy ^, proceeding from the yield condition formulated in the expressions σ_x ^, σ_x ^, σ_xy ^

The transition from the stress space to the stress space is a rather difficult task, often impossible due to the impossibility of integrating the stress condition over the shell thickness.

There are various simplifying hypotheses and models, for example, a three-layer solid shell model, which allows one to obtain an acceptable solution in some cases. The content of this problem is beyond the scope of this dissertation work, therefore, here we will restrict ourselves only to conclusions about the diversity and possible irregularity of the fluidity conditions, which should be analyzed.

As can be seen from the description of mathematical models of limiting equilibrium problems, equilibrium conditions play an important role in them. They are usually written in differential form [2]:

$$\begin{cases} \frac{\partial N_x}{\partial x} + \frac{\partial N_{xy}}{\partial y} = 0\,; \qquad \frac{\partial N_y}{\partial y} + \frac{\partial N_{xy}}{\partial x} = 0\,; \\ \frac{\partial^2 z}{\partial x^2} N_x - 2\frac{\partial^2 z}{\partial x \partial y} N_{xy} + \frac{\partial^2 z}{\partial y^2} N_y + \frac{\partial^2 M_x}{\partial x^2} - 2\frac{\partial^2 M_{xy}}{\partial x \partial y} + \frac{\partial^2 M_y}{\partial y^2} - q = 0 \end{cases} \qquad (5)$$

These are partial differential equations.

Since the goal of the solution is the definition in the final form of expressions for all internal efforts, the problem is reduced to integration (5). Instead of analytical methods, numerical methods are often used, and then they resort to some kind of discretization of relations (5) -wave or corpuscular.

For example, the transition from differential to algebraic relations is possible using finite differences.

Let us first consider a particular case without an instant problem statement. From (5) with M_x ^ = M_y ^ = M_xy ^ = 0, we obtain

$$\begin{gathered} \frac{\partial N_x}{\partial x} + \frac{\partial N_{xy}}{\partial x \partial y} = 0\,; \qquad \frac{\partial N_y}{\partial y} + \frac{\partial N_{xy}}{\partial x \partial y} = 0\,; \\ \frac{\partial^2 z}{\partial x^2} N_x - 2\frac{\partial^2 z}{\partial x \partial y} N_{xy} + \frac{\partial^2 z}{\partial y^2} N_y + q = 0. \end{gathered} \qquad (6)$$

where Z (X, Y) is the equation of the median surface in Cartesian coordinates;

q is the intensity of the distributed load normal to the median surface.

Draw a regular grid with a square cell on the area occupied by the shell. For the node with the number i, j, we obtain from the first and second equations (6), using the one-sided differences

$$(N_x)_{i-1,j} - (N_x)_{i,j} + (N_{xy})_{i,j-1} - (N_{xy})_{i,j} = 0,$$

$$(N_y)_{i,j-1} - (N_y)_{i,j} + (N_{xy})_{i-1,j} - (N_{xy})_{i,j} = 0. \qquad (7)$$

In the third equation (6), the coefficients under the efforts N_x ^, N_y ^, N_xy ^ are the curvatures of the middle surface, which are constant or varying from node to node. It is important to note that the system formed by the third equation (6) and equations (7) is an algebraic system of linear equations. Denoting the curvatures

$$K_x = \frac{\partial^2 z}{\partial x^2}\,; \qquad K_y = \frac{\partial^2 z}{\partial y^2}\,; \qquad K_{xy} = \frac{\partial^2 z}{\partial x \partial y}$$

and moving on to dimensionless efforts

$n_x = N_x\ N_0^{-1}$; $n_y = N_y\ N_0^{-1}$; $n_{xy} = N_{xy}\ N_0^{-1}$; $N_0 = \sigma_0\ k\ h$,

h is the thickness of the shell, we obtain a system of linear equations for the mesh node with the number

$$(k_x\ n_x)_{i,j} - 2(k_{xy}\ n_{xy})_{i,j} + (k_y\ n_y)_{i,j} + q_{i,j} = 0,$$

$$(n_x)_{i-1,j} - (n_x)_{i,j} + (n_{xy})_{i,j-1} - (n_{xy})_{i,j} = 0, \quad (8)$$

$$(n_y)_{i,j-1} - (n_y)_{i,j} + (n_{xy})_{i-1,j} - (n_{xy})_{i,j} = 0.$$

An equation of the form (8) can be written for each node of the grid area.

In a more general case, that is, in the moment theory of shells, to represent the second derivatives of the moments in the third equation (5), we use the second differences. For a point with a number, we get

$$\frac{\partial^2 m_x}{\partial x^2} = \Delta x^{-2}\ [(m_x)_{i-1,j} - 2\,(m_x)_{i,j} + (m_x)_{i+1,j}],$$

$$\frac{\partial^2 m_y}{\partial y^2} = \Delta x^{-2}\ [(m_y)_{i,j-1} - 2\,(m_y)_{i,j} + (m_y)_{i,j+1}], \quad (9)$$

$$\frac{\partial^2 m_{xy}}{\partial x \partial y} = \frac{(m_{xy})_{i-1,j-1} + (m_{xy})_{i,j} - (m_{xy})_{i-1,j} - (m_{xy})_{i,j-1}}{4\Delta X \Delta Y}.$$

Here ΔX, ΔY is the grid step in each direction, the quantities m_x ^, m_y ^, m_xy ^ are dimensionless bending moments introduced by the formulas

$$m_x = \frac{M_x}{M_0};\ m_y = \frac{M_y}{M_0};\ m_{xy} = \frac{M_{xy}}{M_0};\ M_0 = \frac{\sigma\, h^2}{4}$$

Substitution of relations (9) into (5), replace the third equation with the corresponding algebraic expression. It is important to note here that all algebraic equations obtained by grid discretization are linear with respect to the efforts n_x, n_y, m_{xy}

Consider the ¼ part of the shell, square in plan. Figure 1 shows the finite difference mesh and the numbering of its nodes. Composing the equilibrium equations (5) in algebraic form, we take into account that (8) - the equilibrium equations must be made only for loose nodes of the shell. If we assume that the shell is supported on four sides, then the equilibrium equations will be compiled only for the internal nodes 1, 2 and 4. Since for each node we compose three equilibrium equations, we will get nine algebraic equations in total:

the symmetry conditions of the problem allow, when drawing up the equilibrium equations, to identify the nodes (Fig. 1 b) 2 and 7, 3 and 8, 9 and 5, as well as 7 and 10, 4 and 11, 2 and 13, 4 and 14, and due to this simplify equations noticeably;

• the conditions for fixing the edges allow you to immediately indicate the values of internal forces at the points of the mesh coinciding with the contour, for free feathering of the edges at

x=±a, N_x =0, M_x =0, N_y ≠0 и т.п.

y=±a, N_y =0, M_y =0, N_x ≠0 и т.п.

For definiteness, let the middle surface of the shell be an elliptic paraboloid

$$Z = \frac{f}{2a^2}\left(x^2 + y^2\right) \qquad (10)$$

where 2a is the size of the shell side in plan; f-boom lift.

Calculating the curvature of the middle surface, we find

$$K_x = \frac{\partial^2 z}{\partial x^2} = \frac{f}{a^2},$$

$$K_y = \frac{\partial^2 z}{\partial y^2} = \frac{f}{a^2}, \qquad (11)$$

$$K_{xy} = \frac{\partial^2 z}{\partial x^2} = \frac{f}{a^2} = 0.$$

In order to construct a promising procedure for calculating the bearing capacity of rigid-plastic shells based on linear software methods, it is necessary to obtain linear approximations in the form of bodies bounded by sections of hyperplanes (polyhedrons) instead of curvilinear yield conditions. The problem of such linearization contains the following aspects.

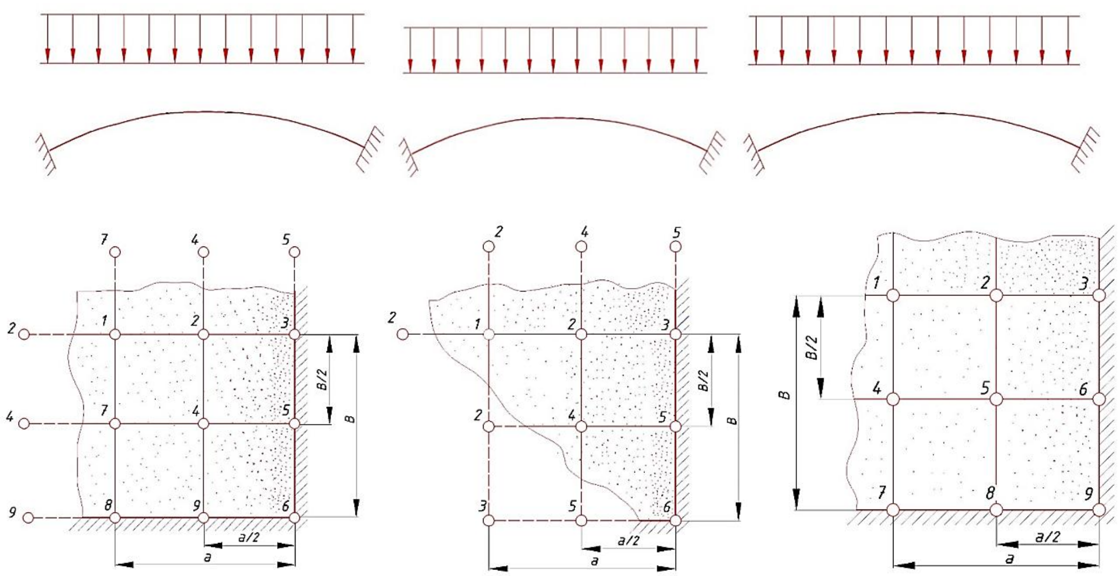

Fig.1

1. The linearization technique should be suitable for both regular and piecewise regular surfaces.

2. In order to control the details in the approximation of hypersurfaces by polyhedra, it is necessary to construct both inscribed and described ones each time.

3. The size of the problem, the amount of computation and computer time per metro depend on their number of polyhedron faces and increases sharply with an increase in their number. Therefore, the question arises about the choice of the optimal number of faces, which allows you to obtain the specified accuracy of calculations for unnamed time spent.

So, we have the coefficient of the faces of the secant or tangent polyhedra, which is the elements of the main matrix - the matrix of the plasticity condition in the linear programming problem, which in turn calculates the lower bound for the carrying capacity of the covering shells. The calculated results are shown in Fig. 2.

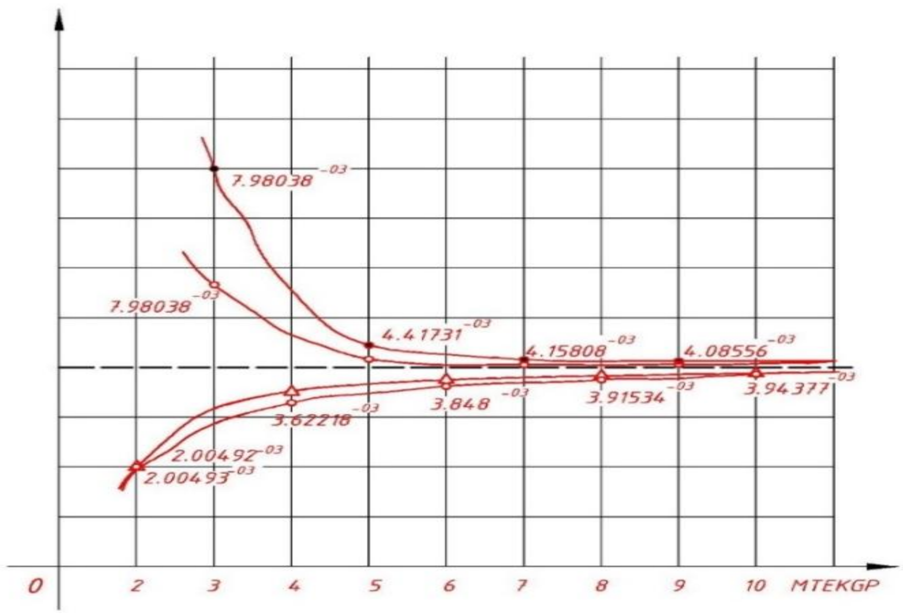

Fig.2

This approach makes it possible to consider from the same positions not only regular, but also piecewise smooth flow conditions, for example, conditions with "limited interaction" (3).

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