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GEOMETRIC DESIGN OF FORMWORK FROM TRANSFORMABLE PANELS FOR THE CONSTRUCTION OF SHELLS OF DOUBLE CURVATURE

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Abstract: This article describes the research work on the calculation of structural elements in the monolithic method of manufacturing shutters-shells with a two-sided curvature of the transforming formwork, as well as comments on the organization of construction and installation works.

Keywords**:** Formwork, shells, monolith, approximation, unification, shaping, elliptical, conical, cylindrical, patterns, algorithm, transformation.

Formwork design for the construction of shells drawn on surfaces of double curvature is a complex and time-consuming process. In the construction of multi-dimensional coatings in the CIS and abroad, single-use formwork is used, the installation of which involves significant funds. In this regard, there is a need to create a formwork system that would make it possible to reuse its individual elements, simplify the transportation, installation and dismantling of components, and thus significantly reduce the cost of erecting monumental shells.

One of the solutions to the problem is the creation of a formwork system with form-building elements in the form of transformable panels. Such shields in the working position can take the form of compartments of cylindrical and panicked surfaces with an arbitrary-shaped guide, and after removing the loads, return to a flat state, convenient for transportation. They lend themselves well to analytical description, smoothly joining each other along rectilinear generators in one direction and with a break along common guides in the other (Fig. 1). The property of the generators of these surfaces intersects at one proper or non-proper point opens up wide possibilities for the unification of individual elements. Using them as parquet elements, it is possible to increase the accuracy of approximating surfaces of double curvature, predict and correct the shape of parquet slab development in advance, and easily find analytical expressions that describe the boundary development curves.

Based on the study of the correspondence of curved lines on surfaces of double curvature of the second and fourth order, the development of approximation schemes, types of stacking elements in the form of cone cylinder compartments suitable for modeling surfaces of various shapes and classes are identified. The method of designing a formwork system based on forming elements from compartments of developed surfaces is shown in Fig.1.

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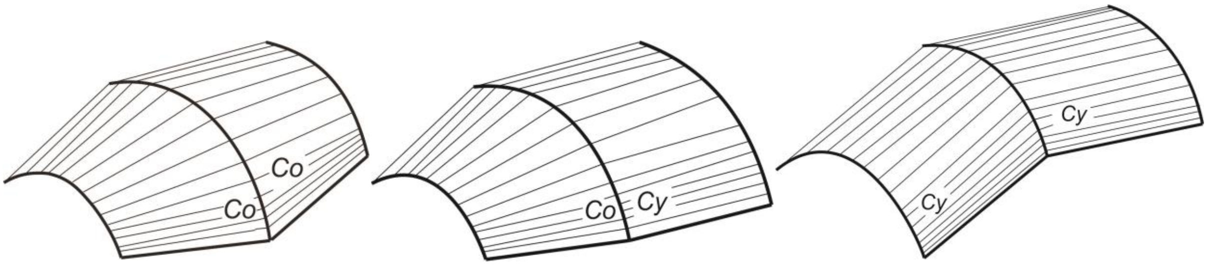

Fig.1.

Since the main and most time-consuming stage in the process of designing formwork for the construction of shells of double curvature is the creation of a shaping surface, or a deck that would meet the requirements of architects, designers and technologists, it is necessary to calculate the main geometric parameters of the formwork composite surface. The design begins with an analysis by the design engineer of the initial data and is conditioned by a number of factors: a variety of packaging elements and their specific application in each individual case, the choice of an approximation scheme for the initial surface (since the sign of the Gaussian curvature of the shell in a certain way affects the calculation), the influence of the shell contour on the preliminary selection of design elements.

To calculate the shaping surface of a formwork made up of torso compartments, a scheme is needed that would simply interpret the geometric model of the formwork. As such a scheme, we take a flat area δ bounded by a guide surface and a support contour, and analyze it using the example of an ellipse - an elliptical surface - a surface of positive Gaussian curvature (Fig. 2).

The first stage of the calculation is to find the rational dimensions of the main parking element. As a result of solving an optimization problem, where the objective function is an expression (co- indicator cost).

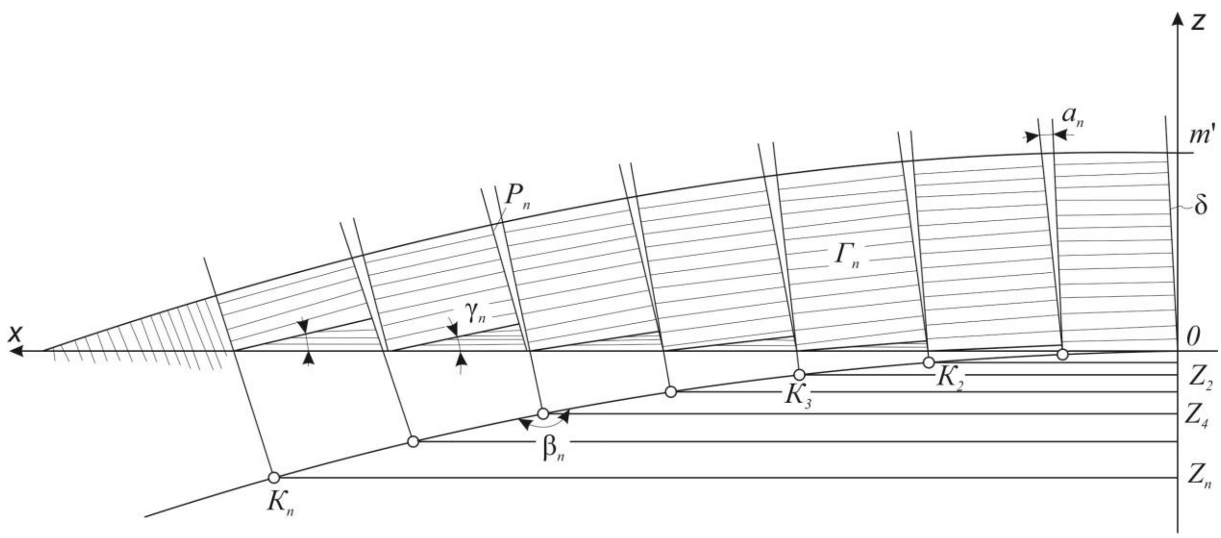

Fig.2.

$U = (c_o K_s + T_o K_t)\delta_n \rightarrow min.$ (1)

T_o - Labor intensity indicator; K_s, K_t - weight coefficients, which are subject to constraints of the form $\sqrt{K_s^2 + K_t^2} = 1$;

δ – Approximation accuracy index; n - coefficient of commensurability, we find the rational dimensions of the shield a and b. The thickness of the shield is determined on the basis of a study of the strength characteristics of the main shaping element, depending on the material of the shield and

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the loads on it, the thickness is found, which can provide a given accuracy of reproduction of a monolithic shell.

The next design stage is the approximation of the curve *m* - a broken line, with a link size equal to *a*, and the direction of its links will coincide with the direction of the generating torsos that package the original surface. The area δ is filled with three types of elements: Rectangles G_n, triangles P_n with angle δ_n and triangles A_n with angle γ_n. Angles α_n and γ_n, as can be seen from Fig. 2, are interconnected, but depend on the curvature of the curve. To ensure the multiplicity of angles, an algorithm for approximating a polyline curve with an angle between links equal to $\beta_n = 180 - n\alpha$ is proposed. To determine the vertices of the approximating polyline, a graph is used - a tree, the initial vertex of which is the origin. The following restrictions are imposed on the graph: it has four edges of equal length; the angles between the edges are 2^o. In this case, the coordinates of the subsequent vertices of the graph can be represented as:

$$Z_{n+1}^{tk} = l * sin\gamma_n^{tk} + Z_n, x_{n+1}^{tk} = l * cos\gamma_n^{tk} + x_n, \qquad (2)$$

$$t=1, 2, 3, 4.$$

The measure of proximity of the graph vertices to the curve *m* is given as follows:

$$d_{tk} = \sqrt{(x_{n+1}^{tk} - x_{tk})^2 + (Z_{n+1}^{tk} - Z_{tk})^2},$$

$$Z_{tk} = f + \lfloor f^2 - (Ax_{tk}^2 + f^2 + C)\rfloor * B. \quad (3)$$

Having received the values of d_{tk}, we compare them. If $d_{2k} < d_{1k} < d_{tk}$, then we take the angle γ_n^{2k} as the calculated one, and take K_{n+1}^{2k} as the support of the graph vertex used for subsequent calculations.

Having the coordinates of the vertices of the polyline, with the help of a number of analytical dependencies, it is possible to determine the projections of all the necessary design parameters of the shaping surface of the formwork. As a result, we obtain a stacking of a flat region δ with three types of elements. In space, these are also three types of approximating elements, which are compartments of cylindrical and conical surfaces of the fourth order. To derive the equation of a composite surface representing the shaping surface of the formwork, the equation of the first design section of the original surface of the shell is sufficient.

One of the important issues in the design of formwork for the construction of shells is the question of the relationship between shaping and supporting elements. When developing a geometric model of a transformable formwork for the construction of shells of double curvature of the fourth order, it is necessary to redefine the framework of flat curved lines of the original surface. As a result of the reassignment, the composite surface is a deck consisting of cylinder compartments and cones of the fourth order. To model one guide of a fourth-order cylindrical or conical surface, it is necessary to fix at least 14 points of the curve with supporting elements. This approach dramatically reduces the effectiveness of the developed formwork system. Therefore, a repeated adjustment of the frame is proposed, which allows one side of the shield to reduce the number of supporting ones to two.

At the next design stage, the engineer will have to solve the problem of obtaining a pattern of a unified additional element, with the help of which the curvature of the forming surface of the formwork varies. The proposed design of the formwork, the algorithm of its geometric modeling, low requirements for

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the accuracy of building a sweep made it possible to propose a discrete method for obtaining a pattern of an additional form-building element that is quite easy to calculate.

It is based on two main ratios:

$$xR_n = \int \frac{Z_n + PH}{\sqrt{1+(f'(z))^2 dz}}, yR_n = \int \frac{Z_n' + kx_n'}{\sqrt{1+k^2}} Z_n + H. \quad (4)$$

In this case, the set of points (xR_n, yR_n) will represent the sweep contour ¼ of the forming element.

On the basis of geometric algorithms, an application package has been created that serves the process of designing a formwork for the construction of shells of double curvature at the stage of a technical project from entering the initial data to obtaining all the necessary design and design characteristics of the shaping surface of the formwork, schemes for arranging the connections of bearing and supporting elements.

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