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Advance Analysis of the Intense-Deformed Condition of Crossing Sectors of Thin Shells with Method of Global Elements

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Abstract* - Spatial structures are designed to change the architectural appearance of our cities, to contribute to the creation of expressive architectural complexes of industrial and cultural structures. Airports and train stations, congress halls and business centers, offices and banks, commodity exchanges, wholesale and retail warehouses, supermarkets and markets, exhibition pavilions, cinema and concert halls and sports complexes, as well as various engineering structures - this is far from complete a list of objects in the upcoming construction of which the use of spatial structures will be required. The rapid development and widespread use of thin-walled reinforced concrete spatial structures became possible thanks to significant advances in the theory of calculating shells and folds, the use of electronic computing technology, as well as the implementation of comprehensive and improved methods for the construction of large-span structures. In world practice, a clear trend is the use of spatial structures of various forms, giving expressive architectural samples and solving functional problems. it is important to calculate shells of shells sometimes indispensable in the construction of special structures. The analytical methods for calculating shells known in the literature become unacceptable for shells of complex shapes. The complexity of the shell shape may be due to the complexity of the outline of its middle surface and the complexity of the outline of its contour (boundary) lines. It can also be caused by the formation of the surface of the shells as a combination of several simple surfaces. The need to give the casings a special shape is dictated by various factors. The problems of studying the elastic equilibrium of shells are associated with certain mathematical and technical difficulties, since their stress-strain state is described by high-order equations with variable coefficients. One of the directions of modern structural mechanics is the introduction of new forms of thin-walled spatial structures into engineering practice. At the same time, the study of the geometry of these shapes, the development of methods for calculating shells of complex geometry is one of the main tasks of this direction. Shell fillets, which are a class of complex geometry surfaces, provide great opportunities for creating striking architectural shapes.

***Index Terms* - Spatial structures, Thin shell, Architectural expressiveness, Mating shells.**

I.INTRODUCTION

Thin-walled 3D structures' designs of type of shells are the most economic designs and find wide application in the industries: such as chemical, mechanical engineering, instrument making, construction of industrial and civil buildings. It speaks those shells combine in themselves relative make ease with high durability. It is most widely used classical types of thin-walled designs: shell of rotation cylindrical and conic shells, flat and folded shells on which methods of calculation there is an extensive literature. However, in practice there is a necessity of use and more complex 3D forms, including 3D designs from crossed sectors of shells of identical or various geometry.

Determinatives at application of this or that form of shells for the various purposes can serve:
1. Architectural expressiveness – at a covering of sports complex constructions and public buildings.
2. Design feature – at a covering of wide-span public and industrial buildings without intermediate support that allows to modernize technological processes with the minimal expenses of work and time.
3. A technology requirement – at designing the equipment of the chemical industry, the spiral chamber and a sucking away pipe of waterwheels, etc.
4. Influence of an environment plays a special role at a choice of the optimum form of an environment in aviation and shipbuilding as the geometry of the case

should provide the least resistance of an environment, durability and reliability of a design as a whole.

Methods of calculation of a design of complex geometrical forms are developed insufficiently. Surfaces of interfaced sectors of shells give ample opportunities of creation of an extensive class of new constructional forms. It consists in development of methods of calculation and research of the is intense-deformed condition of crossed compartments of environments. Designing of environments of various outlines on the basis of these surfaces, realization on the COMPUTER of a numerical method of calculation of shells and carrying out of calculation of crossed sectors of Shells. The algorithm of calculation and program complex by calculation of crossed sectors of shells on the basis of Variation-Differentiation method and a method of global elements can be used directly in practice of real designing of the thin-walled environments executed from a linearly elastic material. On uniform algorithm Variation-Differentiation method and a method of global elements it is possible to solve problems of calculation of crossed environments, and so the designs consisting of environments and flat elements.

II OBJECTIVES OF THE CURRENT STUDY

The following are the main objectives considered for this research

1. To design thin wall from crossed compartments.
2. To calculate crossed compartments of environment with application of method.
3. To develop the algorithm of calculation of crossed compartments of environment by method of global elements.

III METHODOLOGY USED FOR THE STUDY

The algorithm Variation-Differentiation method of calculation of plates and shells of complex geometry is described. Calculation of such designs is carried out, basically, various numerical methods, in particular, method of final elements widely widespread in last decades. Variation-Differentiation method principle Lagrange – a principle of a minimum of full energy of deformation is considered.

$$Э = U - A \qquad 1$$

Where U - potential energy deformation; And A - work of external forces.

Potential energy of deformations of environments can be presented in the form of two composed

$$U = U_T + U_u, \qquad 2$$

Where U_T, U_u – potential energy tangential and bending deformations, accordingly, also can be written down in the form of:

$$U_T = \frac{1}{2}\int_{\Omega} \bar{T}^* \bar{\varepsilon}\, d\Omega, \qquad U_u = \frac{1}{2}\int_{\Omega} \bar{M}^* \bar{\chi}\, d\Omega. \qquad 3$$

Here * - a sign on transposing of a vector (matrix). Vectors of deformations and vectors of internal efforts have three components:

Where T1, T2 - normal tangential efforts; T3=S - tangents tangential efforts; ε_1, ε_2 - tangential linear relative deformations; $\varepsilon_3=\gamma_{12}$ - relative tangential deformations of shift of a median surface of an environment; M1, M2 - the bending moments; M3=M12

$$\bar{T} = \begin{Bmatrix} T_1 \\ T_2 \\ T_3 \end{Bmatrix}, \quad \bar{\varepsilon} = \begin{Bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \end{Bmatrix}, \quad \bar{M} = \begin{Bmatrix} M_1 \\ M_2 \\ M_3 \end{Bmatrix}, \quad \bar{\chi} = \begin{Bmatrix} \chi_1 \\ \chi_2 \\ \chi_3 \end{Bmatrix}, \qquad 4$$

Where T1, T2 - normal tangential efforts; T3=S - tangents tangential efforts;

ε_1, ε_2 - tangential linear relative deformations; $\varepsilon_3=\gamma_{12}$ - relative tangential deformations of shift of a median surface of an environment; M1, M2 - the bending moments; M3=M12 – the twisting moment; χ_1, χ_2 changes of the main things environments; $\chi_3 = 2\chi_{12}$ - the double change of curvature of torsion of an environment.

Work of external forces is defined under the formula

$$A = \int_{\Omega} \bar{q}^* \bar{u}\, d\Omega + \sum \bar{p}_i^* \bar{u}_i, \qquad 5$$

Where, $\bar{q}$, $\bar{p}$ - vectors of projections of the distributed superficial loading and the concentrated forces on superficial system of coordinates and on a normal to a surface; $\bar{u}$ - a vector tangential and normal moving of a median surface of an environment; $\bar{u}_i$ - too in a point of action of the concentrated force $\bar{p}_i$.

Minimizing full energy of deformations, it shows system of the algebraic equations as a result of solving nodal deformations. To calculate Tangential and bending deformations the variation differential method is used and for calculation of tangential forces and the bending moments the Hooke 's la w is used.

As in system of the equations characteristics curve enter (factors of square-law forms, the main things of curvature), the library of flat curves which includes parametrical formulas of curves and their three first derivatives are created. Such library allows to calculate automatically all characteristics of directing and forming curves which it is used in the program. The library can replenish. The algorithm of calculation of derivatives of any order, private two functions is developed for reception of necessary characteristics.

The algorithm and the program Variation-Differentiation method in a combination to a method of the global elements, developed in FORTAN for research of units of stationary sea platforms is marked, that, considered an opportunity of crossings of flat elements (plates) and compartments of flat and cylindrical environments. Research of tensely deformed condition of crossings of sectors of complex geometry demands completion of algorithm of a method of global elements. Two variants of interface of compartments are possible**:** 1. Compartments of environments of various geometrical structure are interfaced on a line, a being coordinate line of both environments. Such designs are possible, in particular, at formation of compartments of environments in the form of cyclic, irregular or carved surfaces of Mongue, shell rotations (vessels), and also interface of some types of pipelines of various diameters. Calculation of designs from repeating compartments of environments of identical structure is possible also.2. Crossing of environments passes on the any curve, not being coordinate line of environments. For example, at crossing cylindrical environments.

For calculation the grid so that on a line of interface unit's Different sets sectors of shells are coincided is put on sectors of shell. For the first variant of interface the line of crossing of compartments is known and it is necessary cares of concurrence of only coordinate network crossing a line of interface, i.e. it is necessary to observe an identical step different grids of both sectors on a line of crossing**.**

For the second variant, it is necessary to define preliminary a line of crossing of sectors, and to observe an identical step of corresponding coordinate networks of each compartment on a line of crossing. This problem demands special consideration, depending on geometry of crossed sectors. This problem in the given work is not considered. The algorithm of calculation of crossed shells of sectors if such network on a line of crossing of environments is received, in work is considered and realized in a program complex.

Let median surfaces of compartments of environments are set radius-vectors and, where and – parameters $\bar{\rho}_1(u_1,v_1)$ и $\bar{\rho}_2(u_2,v_2)$, where u_1,v_1 и u_2,v_2 Orthogonal coordinate networks of median surfaces of the first and second compartments accordingly (fig. 1); A_1, B_1 и A_2, B_2 - factors of 1-st square-law form of compartments.

If also u_1,v_1 and u_2,v_2 coordinates of the general unit of compartments on a line of crossing,

$$\bar{e}_{12} = \frac{1}{B_1}\frac{\partial\bar{\rho}_1(u_1,v_1)}{\partial v_1}; \quad \bar{e}_{13} = \bar{e}_{11}\times\bar{e}_{12}. \qquad 6$$

Individual vectors of tangents to coordinate lines and individual normal of the first sector in unit and

$$\bar{e}_{11} = \frac{1}{A_1}\frac{\partial\bar{\rho}_1(u_1,v_1)}{\partial u_1}$$

$$\bar{e}_{21} = \frac{1}{A_2}\frac{\partial\bar{\rho}_2(u_2,v_2)}{\partial u_2}; \quad \bar{e}_{22} = \frac{1}{B_2}\frac{\partial\bar{\rho}_2(u_2,v_2)}{\partial v_2};$$

$$\bar{e}_{23} = \bar{e}_{21}\times\bar{e}_{22}. \qquad 7$$

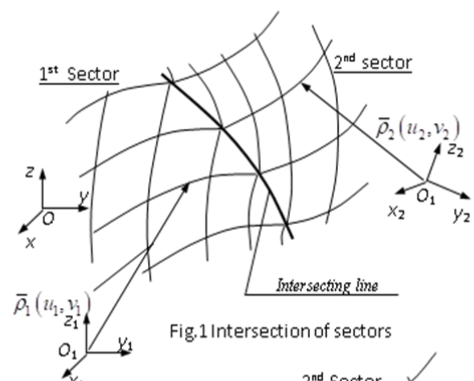


Fig.1 Intersection of sectors

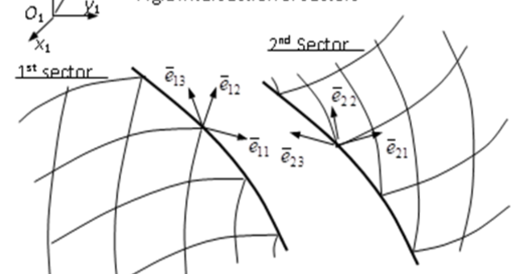


Fig 2. Orthos of local system coordination

The matrix of transformation of one local systems of coordinates in global is defined by system directing cosines or scalar products ortho of two systems

$$[Cs]=\begin{bmatrix}\alpha_{11} & \alpha_{12} & \alpha_{13}\\ \alpha_{21} & \alpha_{22} & \alpha_{23}\\ \alpha_{31} & \alpha_{32} & \alpha_{33}\end{bmatrix}, \quad 8$$

Where. $\alpha_{ij}=\alpha_{ji}=\left(\bar{e}_{1i}\cdot\bar{e}_{2j}\right)$

If projections of a vector in the first system of coordinates – P_{1i} multiplying a matrix of transformation on a vector $[Cs]$ it is received its decomposition in global system of coordinates – P_{ri}

$$\overline{P}=P_{11}\cdot\bar{e}_{11}+P_{12}\cdot\bar{e}_{12}+P_{13}\cdot\bar{e}_{13}=P_{21}\cdot\bar{e}_{21}+P_{22}\cdot\bar{e}_{22}+P_{23}\cdot\bar{e}_{23};$$

$$\left\{P_{ci}\right\}=\begin{Bmatrix}P_{c1}\\ P_{c2}\\ P_{c3}\end{Bmatrix}=\begin{bmatrix}\alpha_{11} & \alpha_{12} & \alpha_{13}\\ \alpha_{21} & \alpha_{22} & \alpha_{23}\\ \alpha_{31} & \alpha_{32} & \alpha_{33}\end{bmatrix}\cdot\begin{Bmatrix}P_{11}\\ P_{12}\\ P_{13}\end{Bmatrix}=[Cs]\cdot\left\{P_{1i}\right\}; \quad 9$$

$$\left\{P_{ci}\right\}=\begin{Bmatrix}P_{c1}\\ P_{c2}\\ P_{c3}\end{Bmatrix}=\begin{bmatrix}\alpha_{11} & \alpha_{12} & \alpha_{13}\\ \alpha_{21} & \alpha_{22} & \alpha_{23}\\ \alpha_{31} & \alpha_{32} & \alpha_{33}\end{bmatrix}\cdot\begin{Bmatrix}P_{21}\\ P_{22}\\ P_{23}\end{Bmatrix}=[Cs]\cdot\left\{P_{2i}\right\} \quad 10$$

The calculation of crossed compartments of environments we shall apply a method of forces. Dismembering compartments on a line of interface, we put in units of compartments on a line of their crossing the equal and opposite directed efforts. A condition of teamwork of compartments are mutual works on a line of crossing and a corner of turn in a plane normal to a line of crossing of compartments, in case of their rigid interface. At hinged connection on a line of crossing last condition is not considered. If moving on a line of crossing of compartments in some directions are fixed, in conditions of interface in these directions are not satisfied and enter into boundary conditions of support conditions of compartments.

It is necessary to consider, that at calculation of crossing compartments of environments the moving connected with a coordinate network of compartments of environments, i.e. with directions of individual vectors in units on a line of crossing - and accordingly are calculated. Therefore, in conditions of interface of moving in units of compartments should be led to the general system of coordinates. For such system of coordinates, the general global system of coordinates can be accepted, or for each unit the local system of coordinates of one of compartments undertakes. Similarly, and efforts in units of interface are put or in a direction of global system of coordinates, or in a direction of local coordinate system of each unit of one of compartments. The second way of a choice of system of joint moving is represented more convenient in case of crossing compartments along the general coordinate line as one of directions of moving will coincide with a direction Tangent to a line of crossing also will be the general for both compartments.

Let's accept for unknown in units on a line of crossing of compartments of effort in a direction of local system of coordinates of the first compartment and the moment

$$Z_m=X_{1,k}; \quad Z_{m+1}=X_{2,k}; \quad Z_{m+2}=X_{3,k}; \quad Z_{m+4}=M_{n,k}, \quad 11$$

Where k – number of unit on a line of crossing, k = 0, 1, Куз; m = 4×(k - 1); (k - 1); Куз – quantity of units on a line of crossing; - effort in k-th unit in a direction of i-th орта; - the moment in a plane normal to a line of crossing. In k-th unit.

The first and second compartment pays off on individual efforts in a direction on a combination of projections of individual efforts in global system of coordinates in units and the individual moment in normal to a line of crossing of a plane.

$$\overline{Z}_{k+i}=1 \quad \rightarrow$$

$$\alpha_{i1(k)}\cdot\bar{e}_{21(k)}+\alpha_{i2(k)}\cdot\bar{e}_{22(k)}+\alpha_{i1(k)}\cdot\bar{e}_{21(k)} \quad 12$$

And the individual moment in normal to a line of crossing of a plane. Here k – number of unit on a line of crossing.

As a result of calculations receive systems of Rotation and corners of turn in units in a plane, normal to a line of crossing from all individual efforts

$$\delta_{(t)mn}=\delta_{(t)\,in}^{(k)}, \quad 13$$

Where t = 1, 2 - number of a compartment; k - number of unit on a line of crossing of compartments; i = 1,2,3 – number of orthos in local system of coordinates in which direction moving is calculated; i = 4 - a corner of turn in a plane normal to a line of crossing; ; m = 4×(k - 1) - a serial number of moving on a line of crossing of compartments; n – number of individual effort from which action moving is calculated.

Besides Rotation and in units of compartments on a line of crossing from the loading operating within the limits of a compartment are calculated. Rotation are calculated in a direction of local superficial systems of coordinates in units of each compartment. For drawing up of conditions of mutual of Rotation, Rotation to units of the first and second compartment are led to projections of Rotation in global system of coordinates.

$$\delta'_{(t)\,mn} = \sum_{l=1}^{3} \alpha_{i\,l(k)} \cdot \delta^{(k)}_{(t)\,l\,n}, \quad m = 4\times(k - 1) + i, \quad i = 1,2,3. \qquad 14$$

Similarly, from loading in the second compartment.

$$\Delta'_{(t)\,mP} = \sum_{l=1}^{3} \alpha_{i\,l(k)} \cdot \Delta^{(k)}_{(t)\,l\,P}. \qquad 15$$

For a corner of turnaround of a normal to a line of crossing (i =4)

$$\delta'_{(t)\,mn} = \delta^{(k)}_{(t)\,4,n}, \quad m = 4\times(k - 1) + 4. \qquad 15.a$$

Then, conditions of mutual work of rotation on a line of interface of compartments will enter the name in the form of:

$$\sum_{n=1}^{4\times K} \left\{\delta'_{(1)mn} - \delta'_{(2)mn}\right\} \cdot Z_n + \Delta'_{(1)\,mP} + \Delta'_{(2)\,mP} = 0$$

$,.\ m = ,2,\ldots 4\cdot K_{уз}$ 16

Solving system of the algebraic equations (11), we define unknown efforts in units on a line of interface of compartments. Further each compartment pays off independently on action of the loading, acting on a compartment and system of efforts in units on a line of interface of compartments.

On offered algorithm of calculation of environments of a method of global elements the program in language the FORTRAN has been realized and test calculations of various designs are lead. The analysis of their results shows good convergence at comparison with known decisions in the literature.

Let's note, that calculation of plates and environments is included in the program on the elastic basis and environments with an aperture, and at insignificant completions Algorithm it is possible to solve problems: plates and environments. At debugging the developed module of the program complex realizing calculation of crossed compartments of environments by a method of global elements test calculations are lead. In particular, calculation of the -sine waves carved environment conditionally broken into two compartments is lead. Results were compared to calculation of the whole compartment. Results of calculations have completely coincided.

The design of the environment, consisting of 4 consistently connected compartments with a median carved parabolic-sine wave surface variable Gausses curvature is resulted. The design cannot be presented by a uniform continuous surface, and pays off as a set of crossed compartments of environments.

Compartment of an environment with a symmetric directing parabola and a sinusoid forming within the limits of two half waves - 0 to 16 m. (fig. 3.m. The module of elasticity of a material, factor of Poisson's of a material; thickness of an environment on lines of curvature was put On a surface of an environment a grid with uniform step in both directions.

IV RESULTS AND ANALYSIS

Calculation of this shell is performed on the action of Dead Load.

When calculating thin-walled structures consisting of compartments of the shells of the same or different geometry on the line of crossing of the compartments occurs a jump-like change in the geometric characteristics of the median surfaces of the shells, which the turn leads to the complication of methods for calculating such structures. In particular, on the contact line of the movement is described for each compartment in its own surface coordinate system. To ensure the continuity of movements on the crossing line of the compartments, it is necessary to constitute conditions of continuity in the global coordinate system for both compartments. In the finite element method, the continuity conditions of the movement on the crossing line of the compartments include in the general system of equations. This leads to systems of high-order equations.

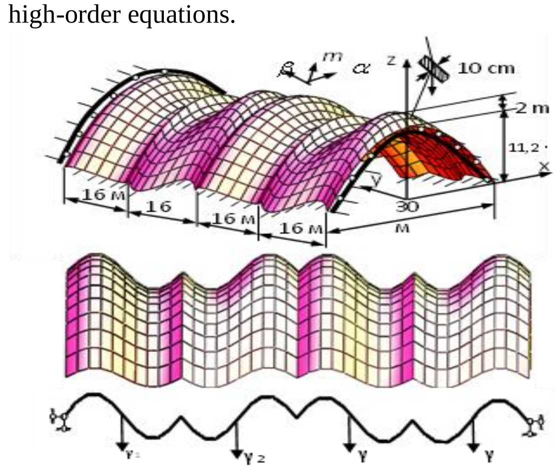
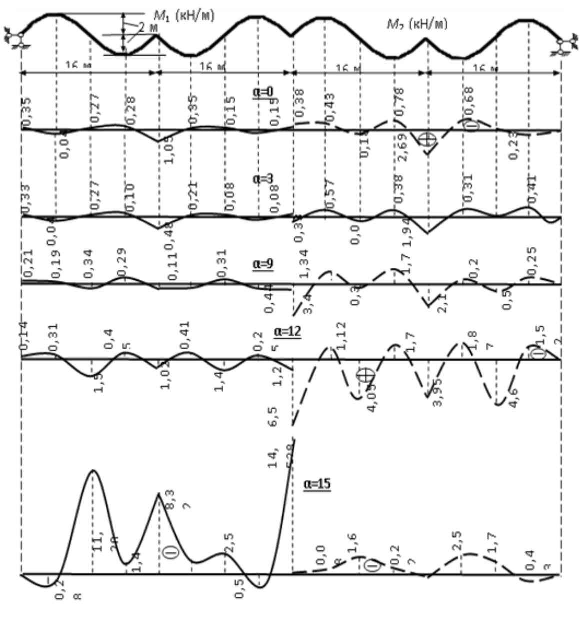


Fig3.



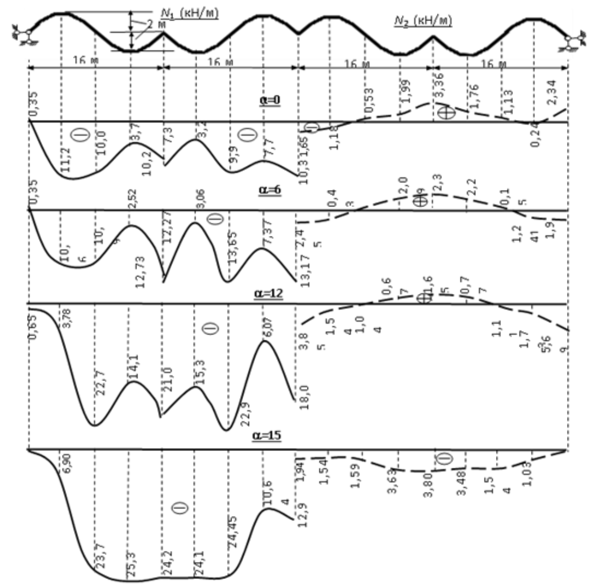


Fig. 4

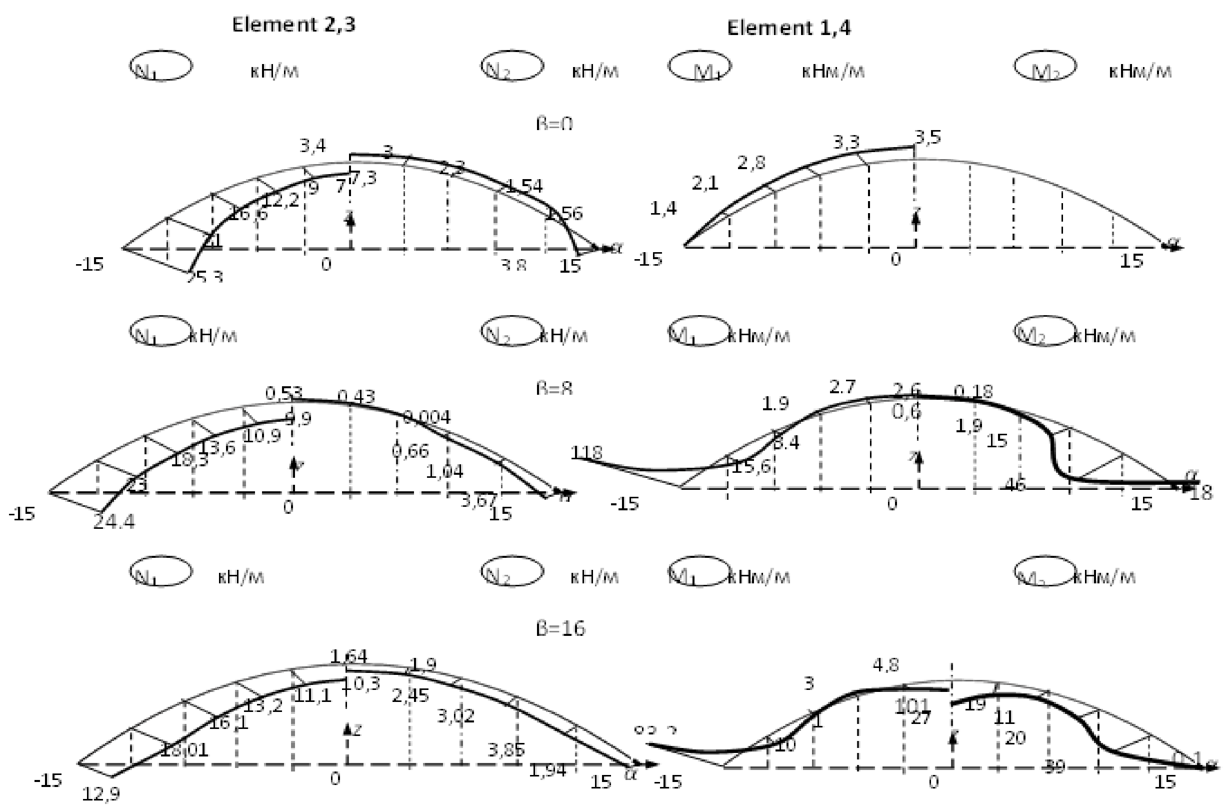


Fig 5

Another approach is the global (super) elements method. The method is that each compartment of the shell is calculated independently on the active load, which is added to the system of forces acting on each compartment on the contact line and ensuring the continuity of displacements. To determine the effort on the contact line of the compartments use the forces method. In the present work, the software complex of the variation and difference method is used to calculate the shell compartments. On each of the intersecting compartments there is a difference grid with shared nodes on the intersection line. Next, the calculations are calculated on the action of the unit forces specified in the nodes of the difference grid on the crossing line in the global coordinate system, and a single moment around tangent to the crossing line of the compartments. From each unit force, movements and angles of rotation in the intersection lines nodes are determined. On the basis of these calculations, a system of canonical singular equations is drawn up in nodes of a difference grid on the line and crossing compartments. From the solution of the system of equations, the actual stresses acting on the crossing lines of the shells are determined. The software complex of the variational-difference method of the shells, added a module that implements the algorithm of the global elements method. The article discusses a thin-walled spatial structure consisting of four sequentially located shell compartments with a median carved surface (Fig. 3). The design cannot be represented by a single continuous surface and is calculated as a set of intersecting compartments of the shells based on the software complex of the variation-difference method and the method of global elements. Consider a thin-wing structure of 4 consecutively connected compartments of a parabolic-sinusoidal carved sheath. The median surface of the shell compartment (Fig. 3) is formed by the movement of sinusoids in the normal plane of the parabola guide - (-15 m< x< 15m), with rise of 11.25 m. and rise of Sinusoid - (C = 2 m - amplitude, B = 8 m- length of the half-wave of sinusoids, (-16m < y <16 m). The axis of the sinusoids perpendicular to the parabola plane. . The cross-section profile of the combined sinusoid is shown in Fig. 4 Next, the surface coordinate system in the curvature lines are used. The elasticity module of the shell material, the Poisson coefficient; Shell thickness. A mesh with a uniform step in both directions (steps) was applied to the surface of each compartment. The shell is rigidly pinched in supporting sections. Opportuning extreme; The left (section) and the right (section) of the shell compartments are extremely fixed. The total size of the shell in terms of 30x64 m; height 13.25 m; Minimum rise at negative curvature is 9.25 m. According to the calculation, it is obtained: movements; Tangential stresses, s; Bending, and torque Diagram of internal stresses are presented in Fig. 4, 5.

From the results of the calculation, it follows those tangential normal forces - compressive, more than an order of magnitude more tangential normal

V CONCLUSION

From this study the following conclusions were made

1. Examples of thin-walled designs from crossed compartments of environments are lead.
2. Conditions of the teamwork, crossed compartments of environments are received.
3. The algorithm of calculation of crossed compartments of environments is developed by a method of global elements.
4. The module of a program complex of calculation thin-walled spatial designs variation-differential method by a method, realizing calculation of crossed compartments of environments is developed.
5. Calculations of crossed compartments of environments with application variation-differential method and a method of global elements on various kinds of loadings are lead.
6. The analysis of the intense-deformed condition of crossed compartments of environments on the basis of the received numerical results is lead.

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