Salimov Shoolim Muzaffarovich
University of Tashkent for Applied Sciences,
Associate professor
E-mail: salimovshoolim@gmail.com
Phone number: +998998760950
Mavlanov Tulkin
National Research University “Tashkent Institute of
Irrigation and Agricultural Mechanization Engineers”,
Doctor of Technical Sciences, Professor
E-mail: tulkinmavlanov@yahoo.com
Phone number: +998998956947

INVESTIGATION OF STABILITY OF CYLINDRICAL SHELLS CONNECTED TO A RING PLATE

Abstract. *The paper presents the statement and methods for solving dynamic problems of multiply connected structurally inhomogeneous shell structures, which make it possible to reduce the problem of calculating a wide class of engineering structures to computer-aided design tasks. On the basis of numerical experiments and multi-parameter analysis of the system as a whole, a number of fundamentally important applied problems have been solved for calculating the dynamic characteristics of oscillations (frequencies, modes, determinant resonant amplitudes and damping coefficients) of special structures depending on the parameters of structural inhomogeneity. The stability of cylindrical shells connected to a ring plate under dynamic loads is also examined. A methodology for comprehensive assessment of deformation properties is proposed with the aim of obtaining the most rational mechanical and geometric characteristics. This is based on mathematical modeling of deformation and relaxation processes.*

Keywords: *research, deformation, coefficient, cylindrical shell, ring plate, stability, dynamic loading, critical pressure, viscoelasticity, computational algorithm.*

Salimov Shoolim Muzaffarovich
Toshkent amaliy fanlar universiteti, dotsent
E-mail: salimovshoolim@gmail.com
Tel: +998998760950
Mavlanov To‘lqin
“Toshkent irrigatsiya va qishloq xo‘jaligini
mexanizatsiyalash muhandislari instituti”
Milliy tadqiqot universiteti,
texnika fanlari doktori, professor
E-mail: tulkinmavlanov@yahoo.com
Tel: +998998956947

HALQALI PLASTINKAGA BOG‘LANGAN SILINDRIK QOBIQLARNING BARQARORLIGINI BAHOLASH

Annotatsiya. *Maqolada ko‘p bog‘lanishli konstruktiv bir jinsli bo‘lmagan qobiqli strukturalarning dinamik masalalarini qo‘yish va yechish usullari taqdim etilgan. Bu usullar muhandislik konstruksiyalarining keng doirasini hisoblash masalasini avtomatlashtirilgan loyihalash masalalariga keltirish imkonini beradi. Sonli tajribalar va tizimning ko‘p parametrli tahlili asosida, umuman olganda, maxsus konstruksiyalarning tebranish dinamik xususiyatlarini (chastotalari, shakllari, determinant rezonans amplitudalari va so‘nish koeffitsiyentlari) strukturaviy bir jinslimaslik parametrlariga bog‘liq holda hisoblash bo‘yicha bir qator prinsipial muhim amaliy masalalar yechilgan. Shuningdek, halqasimon plastinaga ulangan silindrik qobiqlarning dinamik yuklamalar ta’siridagi barqarorligi o‘rganilgan. Eng maqbul mexanik va geometrik xususiyatlarni olish maqsadida deformatsion xossalarni kompleks baholash usuli taklif etilgan. Bu usul deformatsiya va relaksatsiya jarayonlarini matematik modellashtirish asosida ishlab chiqilgan.*

Kalit so'zlar: *tadqiqot, deformatsiya, koeffitsient, silindrik qobiq, halqasimon plastinka, barqarorlik, dinamik yuklama, kritik bosim, qovushqoq-elastiklik, hisoblash algoritmi.*

Салимов Шоолим Музаффарович
Ташкентский университет прикладных наук, доцент
E-mail: salimovshoolim@gmail.com
тел: +998998760950
Мавланов Тулкин
НИУ «Ташкентский институт ирригации и
инженеров механизации сельского хозяйства»,
доктор технических наук, профессор
E-mail: tulkinmavlanov@yahoo.com
тел: +998998956947

ОЦЕНКА УСТОЙЧИВОСТИ ЦИЛИНДРИЧЕСКИХ ОБОЛОЧЕК СОЕДИНЕННЫХ С КОЛЬЦЕВОЙ ПЛАСТИНОЙ

Аннотация. *В работе представлены постановка и методы решения динамических задач многосвязных конструктивно-неоднородных оболочечных структур, позволяющие свести задачу расчета широкого класса инженерных конструкций к задачам автоматизированного проектирования. На основе численных экспериментов и многопараметрического анализа системы в целом решен ряд принципиально важных прикладных задач по расчету динамических характеристик колебаний (частот, форм, детерминантных резонансных амплитуд и коэффициентов демпфирования) специальных конструкций в зависимости от параметров структурной неоднородности. Также исследуется устойчивость цилиндрических оболочек, соединенных с кольцевой пластиной, при динамических нагрузках. Предложена методика комплексной оценки деформационных свойств с целью получения наиболее рациональных* *механических и геометрических характеристик. Она основана на математическом моделировании процессов деформации и релаксации.*

Ключевые слова: *исследование, деформация, коэффициент, цилиндрическая оболочка, кольцевая пластина, устойчивость, динамическая нагрузка, критическое давление, вязкоупругость, вычислительный алгоритм.*

Introduction

Theoretical and experimental foundations of nonlinear rheological properties manifestation in various elements of structurally inhomogeneous, complex multiply connected shell structures are given in fundamental publications [1-12]. Despite this, the assessment of the stress-strain state of shell structures considering inhomogeneous, viscoelastic properties is carried out only within the framework of linear viscoelasticity.

Recently, a number of works have been published [13], which take into account the manifestation of elastic, viscoelastic linear and nonlinear properties of the material of shell structures under dynamic effects. A summary of some of them is given below.

In [13], a calculation model of the foundation base deformation was presented based on the layer-by-layer summation method taking into account the components of the deviator and the ball tensor, the ratio between them being different at different points of the foundation. Nonlinear volume strain of soil over time was considered taking into account the compaction of soil bearing layer.

Dynamic reaction of soil dams [13] was studied with account for nonlinear and viscoelastic properties of soil; the dependence of dynamic reactions on load and mechanical properties of soil was established.

Based on the results of experiments, local laws of interaction of extended underground pipelines and fragments of the outer surface of underground structures with soils of disturbed and undisturbed structure were constructed [14].

In [15], using the nonlinear rheological models, the stress state of the dam was investigated. The possibility of using the model was demonstrated by comparing the numerical results with the results of laboratory tests.

In [16], the generalized rheological models of unsaturated and water-saturated soils were proposed and the corresponding equations were derived, used in quantitative assessment of additional residual strains and stresses in soil. A one-dimensional problem of consolidating a layer of not completely water-saturated soil under cyclic variation in external load was solved.

A model and a set of determinant relations for a rheological model of soft soils were proposed in [17]. The possibility of using this model was confirmed by a number of rheological consolidation experiments under different loading velocities.

In [18], a tendency was shown to increase the instantaneous strain modulus with an increase in creep. A nonlinear creep model has been introduced for soft soils, in which the creep decay was described by a nonlinear hardening function and viscosity coefficient, and the nonlinear creep curves were in good agreement with experimental data.

The behavior of specific structures using the hereditary theory of viscoelasticity under dynamic loading has not been sufficiently studied though widely considered in literature sources [19, 20, 21]. The overwhelming number of publications related to dynamic problems of hereditary theory of viscoelasticity was addressed to the calculation of (linear and geometrically nonlinear) thin-walled structures — beams, plates, and shells [12, 21].

The scheme for solving dynamic problems of viscoelasticity for thin-walled structures is fairly standard. Choosing a coordinate function that satisfies the boundary conditions, the original problem can be reduced to the problem of oscillations of a system with finite number of degrees of freedom, that is, to a system of linear or nonlinear integro-differential equations with one independent time variable [12, 21]. As a rule, trigonometric or beam functions are used as coordinate functions. Such a choice of coordinate functions limits the class of problems to be solved to the structures of the simplest configurations - beams of constant sections, a rectangular plate, a cylindrical shell [12].

The authors of those publications, assuming a number of inaccuracies in coordinate functions selection, tried to increase the solution accuracy of the system of integro-differential equations. However, for structures with real geometry, it is impossible to choose analytical coordinate functions that satisfy the boundary conditions of the problem.

The above review of known works shows the need to assess the stress-strain state and dynamic behavior of structurally inhomogeneous shell designs of earth structures considering not only rheological properties of shell structures, but the heterogeneous structural features and real geometry.

In this paper, we present the methods, algorithm, and results of a study of dynamic behavior of multiply connected structurally inhomogeneous shell structures, taking into account viscoelastic properties of the material under various dynamic effects.

Research Methodology

Multi-connected structures, subjected to external pressure on their cylindrical parts, are being studied for stability. In both structures, the cylindrical shells, with one of their ends rigidly clamped, have identical geometry.

$$L_1/R = L_2/R = 1\,, R/h_ц = 400. \tag{1}$$

The task reduces to finding the minimum value of the critical external pressure load, which we will determine using the formula

$$q = \xi\, q_c\,, \tag{2}$$

where

$$q_c = \frac{\pi\sqrt{6}}{9z}\frac{E}{(1-\nu^2)}\frac{h^2}{R^2}, z = \frac{L\sqrt[4]{(1-\nu^2)}}{\sqrt{Rh}}. \tag{3}$$

Before proceeding directly to the analysis of the entire structure, let us consider the behavior of its individual elements. The total length of the cylindrical part of the structure is $2L$, but due to reinforcement in its middle by a ring plate, which has greater rigidity in the radial direction, we can limit our consideration to only a cylindrical shell of length L. The question remains about the choice of boundary conditions at the junction of the ring plate and the cylindrical part of the structure. These conditions are elastic in nature and can range from hinged support to any other type.

$$\Gamma_6 : w = M_{11} = T_{11} = \vartheta = 0 \tag{4}$$

until firmly clamped

$$\Gamma_1 : w = \theta_1 = u = \vartheta = 0. \tag{5}$$

For combinations of these boundary conditions at the ends of the cylindrical shell, over a wide range of relative length z, it follows from work [2] that the dependencies of the critical parameter $\xi^{¿}$ at $z \geq 10$ practically coincide with the dotted lines in Figure 1, obtained by N.A. Alfutov based on V.Z. Vlasov's semi-momentless theory. Taking into account the actual joint stiffness, the curve describing the dependence of the critical parameter $\xi^{¿}$ on the relative shell length z will lie between these lines.

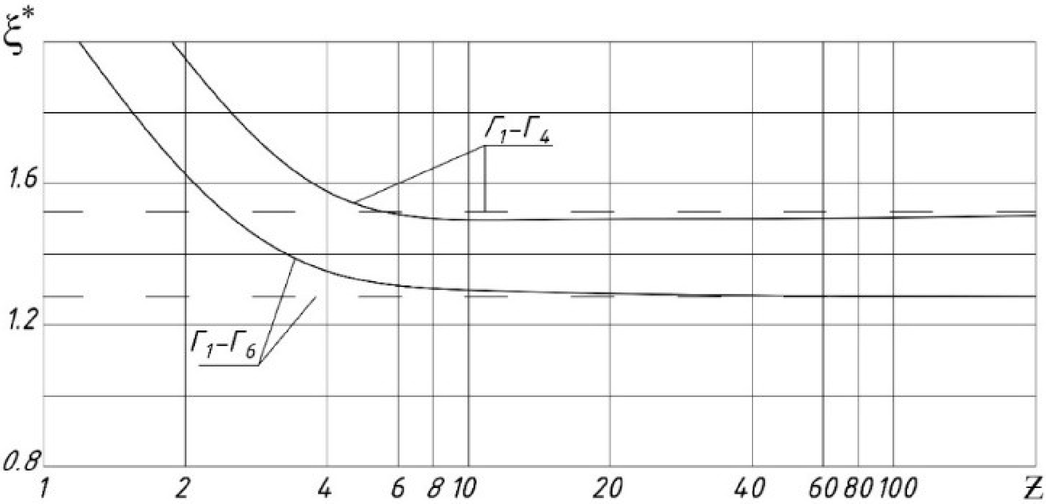

Figure 1

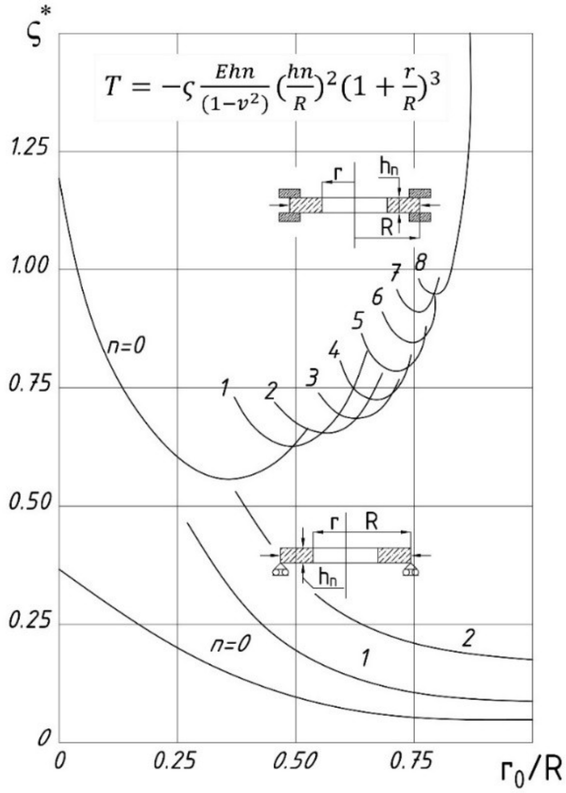

Figure 2

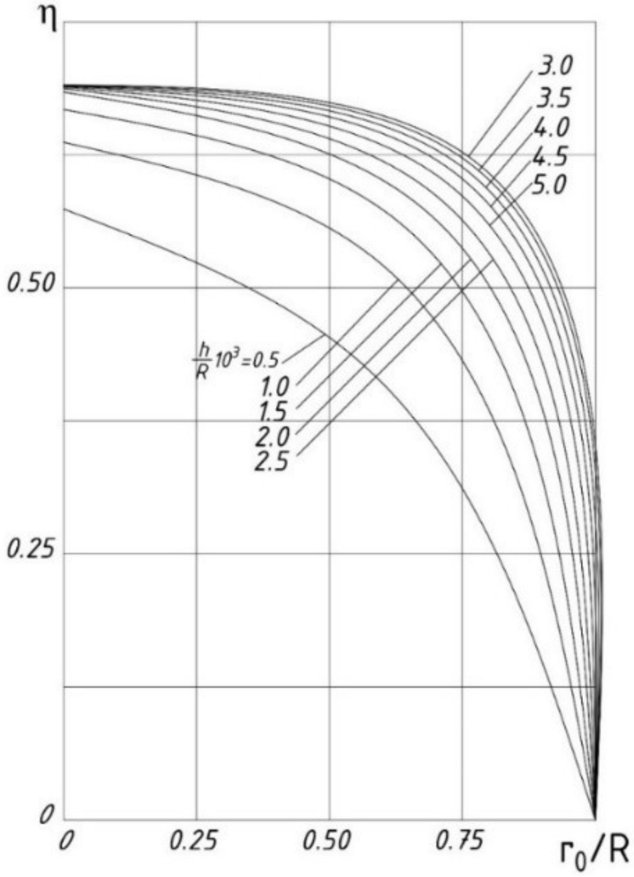

Figure 3

The behavior of an annular plate with a free inner edge under radial compression along the outer edge has been insufficiently studied. Therefore, an investigation was conducted on the stability of an annular plate with two variants of boundary conditions at the outer edge.

$$\Gamma_2 : w = \theta_1 = T_{11} = \vartheta = 0\,, \tag{6}$$

$$\Gamma_6 : w = M_{11} = T_{11} = \vartheta = 0. \tag{7}$$

The magnitude of the critical force was determined using the formula

$$T = -\varsigma^{¿} \frac{E h_n}{\left(1 - \nu^2\right)} \left(\frac{R}{h_n}\right)^2 \left(1 + \frac{r_0}{R}\right)^3 . \tag{8}$$

The dependencies of the critical parameter $\varsigma^{¿}$ across a wide range of inner radius variations for different wave numbers in the circumferential direction are presented in Figure 2.

In the case of hinged support (7), the minimum critical load value is obtained with axisymmetric loss of stability $(n=0)$. However, as $r_0 \to R$, when the plate can function as a ring, a different critical load value with a non-axisymmetric form of stability loss $(n>0)$ becomes possible. In this case, it is necessary to calculate the critical load for the plate using the ring model $(n=2)$.

$$T = 2 h_n E \left(\frac{R - r_0}{R + r_0}\right)^3 \tag{9}$$

and compare them with the values obtained from (8). The minimum value among these will determine the true magnitude of the calculated critical force.

When considering the boundary condition (6), the value of the critical load parameter increases significantly, with its minimum values observed for both axisymmetric $(r_0/R \leq 0.5)$ and non-axisymmetric $(r_0/R > 0.5)$ loss of stability.

In the case of non-axisymmetric loss of stability, the number of waves in the circumferential direction grows as r_0/R increases.

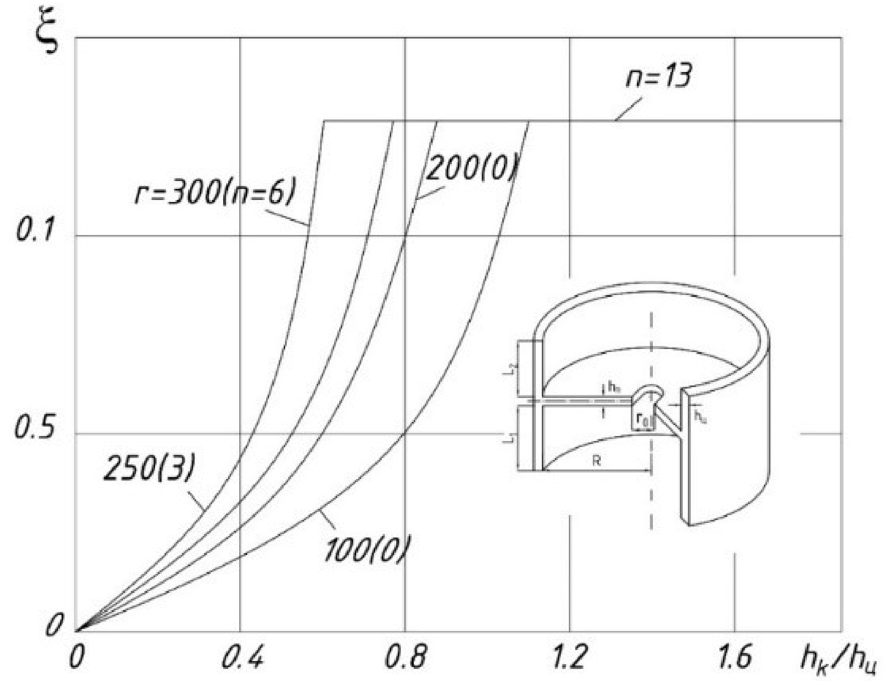

Figure 4

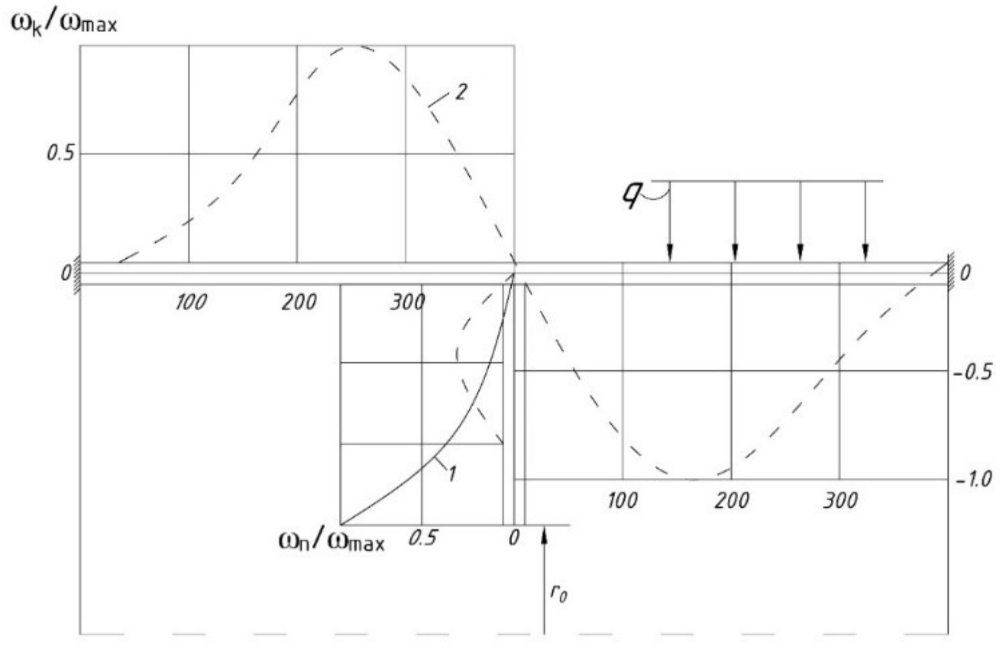

Figure 5

Analysis and results

As a result of studying the stability of the entire structure using the developed method, ξ dependencies related to the corresponding geometry of the annular plate were obtained (Figure 4). Figure 5 shows the forms of stability loss for the structural elements. The shape marked with number 1 in Figure 5 demonstrates that the plate predominantly loses stability. In the geometric domain where all structural elements are clearly involved in the loss of stability (form 2 in Figure 5), the critical load value remains practically unchanged, and the form stays constant with the formation of 13 waves in the circumferential direction. The domains of critical values of $\xi^{\text{¿}}$practically coincide with the values of this parameter for a cylinder of length L, which satisfies the boundary conditions (4) and (5). This confirms that the results of work [2], presented in Figure 1, together with formula (2), can be used to study the stability of the considered multiply connected structure.

In the range of structural parameters where the plate primarily loses stability, it is necessary to establish which dependency or dependencies can be used to limit the investigation of structural stability. To do this, we need to determine the relationship between the critical value dependencies for the plate (8) and (9) and the critical pressure for the entire structure. From the solution of the strength problem, we will determine the force acting on the outer edge of the plate as a function of the external pressure q for various plate geometries. As a result of the calculations, Figure 3 presents the dependencies of the parameter η, through which the force acting on the plate is determined.

$$T=\eta q R \tag{10}$$

Now, considering the specific critical pressure for which the critical force values for the plate are determined from expressions (8) and (9), taking into account (10), it follows that the critical force value coincides with the critical force for the plate with boundary conditions (6) at the outer edge and is determined by formula (8). In other words, when the plate loses stability, the cylindrical shells do not allow it to bend at the outer edge.

Thus, for the analysis of a multi-connected axisymmetric structure (Fig. 4), it is sufficient to have dependencies of parameters $\xi^{\text{¿}}, \varsigma^{\text{¿}}$, and ηon the geometry of the structure (Fig. 1, 2, 3) and expressions (2), (8), and (10). The minimum load value for the entire structure will be the lesser of two pressures: the critical external pressure for a cylinder of length L with boundary conditions (4) and (5), which is determined by formula (2) taking into account the dependence of $\xi^{\text{¿}}$ in Fig. 1, or the external pressure causing the loss of plate stability and determined according to expression (8).

$$q=-\varsigma^{\text{¿}}\eta^{-1}\frac{E}{\left(1-\nu^2\right)}\left(\frac{h_n}{R}\right)^3\left(1+\frac{r_0}{R}\right)^3, \tag{11}$$

where $\varsigma^{\text{¿}}$ is taken from Fig. 2 for the boundary condition (6) at the outer edge.

The form of the structure's loss of stability takes the shape of curve 1 or 2 in Fig. 5, depending on which part of the structure predominantly loses stability.

Conclusions

Thus, this work establishes relationships and dependencies that can be applied to the analysis and design of similar structures across a fairly wide range of geometric parameter variations.

The obtained results allow us to conclude that the proposed theoretical premises model the dynamics of real objects with sufficient accuracy. The developed methodology, algorithm, and calculation program ensure obtaining a solution to the problem with the required precision.

References

1. Myachenkov V I, Maltsev V P 1984 Methods and algorithms for calculating spatial structures on computer Mechanical Engineering p 278
2. Mavlanov T. 2020 Development of methods and algorithms for calculating shell structures taking into account structural inhomogeneity and interaction with various media TIIAME p 200
3. Grigorenko Ya M, Bespalova E I, 1971 Numerical solution of boundary value problems of the statics of orthotropic layered shells of revolution on a M-220 computer Methodological supplies –(Kiev, Naukova dumka) pp 151
4. Grigorenko Ya M, 1973 Isotropic and anisotropic layered shells of rotation of variable stiffness (Kiev, Naukova dumka) 228 p.
5. Grigorenko Y M, Vasilenko A T and Pankratova N D 1977 Calculation of non-circular cylindrical shells (Kiev, Naukova dumka) pp 404
6. Grigorenko Ya M, Mukoed A P, 1979 The solution of problems of the theory of shells on a computer (Kiev, Vishcha shkola) pp 279
7. Grigorenko Ya M, Kitaygorodsky A B, Semenova V V, Sudavtsova G K and Shinkar A I 1980 Calculation of orthotropic laminated shells of revolution with variable stiffness on an computer (Kiev, Naukova dumka) pp 102
8. Grigorenko Ya M, Vasilenko A T 1981 Methods for calculating shells V 4 Theory of shells of variable stiffness (Kiev, Naukova dumka) pp 543
9. Grigolyuk E I, Maltsev V P, Myachenkov V I and Frolov A N 1971 On a method for solving the problems of stability and vibrations of shells of revolution, Reports of USSR Academy of Sciences MTT 1 pp 9-19
10. Maltsev A A, Maltsev V P and Myachenkov V I 1979 Dynamics of axisymmetric shell structures In Applied problems of strength and plasticity Mechanics of deformable systems Interuniversity collection Gorky GSU pp 150 - 158
11. Maltsev A A 1982 Dynamic loading of thin-walled prismatic structures In book Calculation of transport and building structures using computer Proc MIET 618 M MIET pp 16-23
12. Alexandrov A V 1963 The displacement method for calculating slab and beam structures In Proceedings of MIIT Transzheldorizdat 174 4-18.
13. Filatov A N 1974 Asymptotic methods in the theory of differential and integro-differential equations (Tashkent, FAN) p 216
14. Mavlanov T, Karimov A 1979 On the free forced vibrations of the fundamental slabs of silo structures Reports of AS UzSSR series Tech. Sci 4 pp 43-47
15. Vestyank AV, Gorshkov A G and Tarlakovsky D T 1983 Unsteady interaction of deformable bodies with the environment M, AISTI Russian AS 15 pp 69-121
16. Koltunov V P, Mayboroda A S and Kravchuk 1983 Applied mechanics of a deformable solid (Vysshaya shkola) p 350

17. Strength, stability, fluctuations. Handbook, Vol. 10, (edited by Birger I. A) M.:1968
18. Urzhumtsev Yu. S., Mayboroda V. P. 1984 Technical means and methods for determining the strength characteristics of structures made of polymers. Moscow: Mashinostroenie, -168 p.
19. Salimov, Sh.M., Mavlanov, T., Numonov, A. AIP Conference Proceedings, 2023, 2612, 020003
20. Khudainazarov, S., Salimov, S. AIP Conference Proceedings, 2025, 3265(1), 050017
21. Sh M Salimov and T Mavlanov 2020 IOP Conf. Ser.: Earth Environ. Sci. 614 012057