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AN APPROACH FOR ESTIMATING CRITICAL TEMPERATURES OF BUCLING OF SHALLOW CYLINDRICAL SHELLS.

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Abstract

An approach for defining critical temperatures of buckling for a pivotally resting plane cylindrical shell has been considered. Operation in various climatic zones leads to buckling of roof elements of passenger cars. In connection with that, it is necessary to have a theoretical justification of structural solutions taking into account critical temperatures of buckling of shell elements. The roof element of the passenger car should be classified as plane cylindrical shells. An expression for defining critical temperatures by the Bubnov-Galerkin method has been obtained, as well as the equations of plane cylindrical shells proposed by V.Z. Vlasov. The results calculated with the derived expression have been verified by comparison with those obtained by the finite element method (FEM). This comparison has demonstrated satisfactory agreement of these results.

Key words: *Cylindrical shell, FEM, loss of stability,body of aircraft, Bubnov-Galerkin, critical temperature, variational principle.*

The shell elements are widely spread in modern constructions. For example, they are realized in bodies of passenger wagons, aircrafts or watercrafts. Shell element application makes it possible to reduce a mass of transport objects in a construction itself but to keep a required level of rigidity and strength (a problem of decreasing the construction mass is very topical and actual for space industry). In this regard, the engineers have to resolve the problems with theoretical evaluation and mathematical simulation of the behavior of the developed construction under certain operating conditions. For example, operation in various climatic zones leads to buckling of roof elements of passenger cars. In connection with that, it is necessary to have a theoretical justification of structural solutions taking into account critical temperatures of buckling of shell elements. The roof element of the passenger car should be classified as shallow cylindrical shells. According to V.Z. Vlasov [1,12,13,14], a shell is considered as shallow if the lifting height H does not exceed 1/5 of the smallest size in the plan (Figure 1).

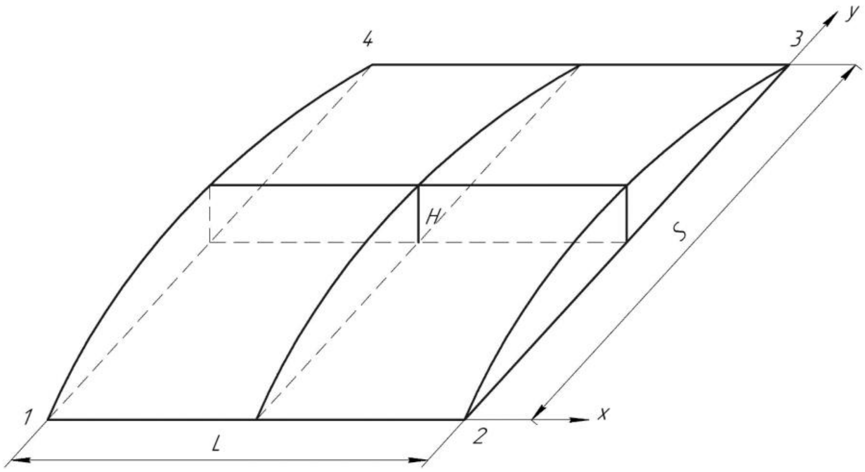

Figure . 1. Rectangular panel of the shallow shell

An approach for theoretical justification of defining critical temperature of buckling of such a shallow cylindrical shell is proposed.

Materials and methods

For this problem to be solved, we apply the general resolving equation usually used for stability of shallow cylindrical shells [2, p.371]

$$D\nabla^8 w + \frac{E \cdot h}{R^2} \cdot \frac{\partial^4 w}{\partial x^4} + N_1 \nabla^4 \frac{\partial^2 w}{\partial x^2} + N_2 \nabla^4 \frac{\partial^2 w}{\partial y^2} = 0 \qquad (1)$$

where $D = \dfrac{E \cdot h^3}{12(1-\upsilon^2)}$ is the cylindrical shell stiffness,

E- is the elasticity modulus of the shell material,
h- is the shell thickness,
υ -is the Poison coefficient,
R- is the radius of the shell curvature,
w- is the radial displacements directed along the normal to the median surface of the shell. In this case, for a shallow shell, the displacements are directed along the radius to the center of the circumference of the cross section,

$$\nabla^4 = \frac{\partial^4}{\partial x^4} + 2\frac{\partial^4}{\partial x^2 \partial y^2} + \frac{\partial^4}{\partial y^4},$$

$$\nabla^8 = \frac{\partial^8}{\partial x^8} + 4\frac{\partial^8}{\partial x^6 \partial y^2} + 6\frac{\partial^8}{\partial x^4 \partial y^4} + 4\frac{\partial^8}{\partial x^2 \partial y^6} + \frac{\partial^8}{\partial y^8},$$

N_1 and N_2 are the axial and tangential linear forces, respectively.

Let us express the values of linear forces N_1 and N_2 through a change in temperature and coefficient of thermal expansion

$$N_1 = N_2 = E \cdot T_{кр} \cdot \alpha_\tau \cdot h \qquad (2)$$

where $T_{кр}$ -is the critical temperature we want to define,
α_τ – is the linear coefficient thermal expansion of the shell material.

In our case, we consider a shell resting with its knuckle joints along the contour; the boundary conditions are satisfied if we take a solution in the following form

$$w = w_{mn} \cdot \sin(\lambda\alpha) \cdot \sin(\mu\beta) \qquad (3)$$

where $\lambda = \dfrac{m\pi}{\alpha_0}$; $\mu = \dfrac{n\pi}{\beta_0}$ are the coefficients,

$\alpha_0 = \frac{L}{R}; \beta_0 = \frac{S}{R}$ is the relative coordinates,

m, n are the coefficients of the series members corresponding to the number of semi-waves to define a shape of buckling,

L and *S* are the shell sizes.

We take one member of the series.

Writing equation (1) in the relative coordinates and taking into account that the compressive linear forces are negative in sign, we obtain

$$D\nabla^8 w + \frac{E \cdot h}{R^6} \cdot \frac{\partial^4 w}{\partial \alpha^4} - N_1 \nabla^4 \frac{1}{R^2} \frac{\partial^2 w}{\partial \alpha^2} - N_2 \nabla^4 \frac{1}{R^2} \frac{\partial^2 w}{\partial \beta^2} = 0 \quad (4)$$

Substituting expressions (2) and (3) into expression (4) and using the Bubnov-Gallerkin variational principle, we obtain:

$$D(\lambda^2 + \mu^2)^4 + E \cdot h \cdot R^2 \cdot \lambda^4 - E \cdot T_{\kappa p} \cdot \alpha_\tau \cdot h \cdot R^2 (\lambda^2 + \mu^2)^3 = 0$$

From the obtained expression, we find T_{kp}

$$T_{kp} = \frac{D(\lambda^2 + \mu^2)^4 + E \cdot h \cdot R^2 \cdot \lambda^4}{E \cdot \alpha_T \cdot h \cdot R^2 \cdot (\lambda^2 + \mu^2)^3}. \quad (5)$$

Thus, we obtain the expression for determining the critical temperature of the shell resting with its knuckle joints on the rectangular panel in case of buckling. Such a panel may represent a fragment of many engineering structures.

Results

As an example, we consider various options for the overall dimensions of the pivotally resting shallow shells, including those with dimensions (900 × 1500) mm, the curvature radius R = 3000 mm and the thickness h = 1.5 mm. These geometric sizes are due to the actual sizes of the roof elements of the passenger car [3,9]. The material is structural low-alloy steel with elasticity modulus $E=2\cdot10^5$ MPa and the coefficient of thermal expansion is $\alpha_T=1{,}2\cdot10^{-5}$ °C^{-1}.

To verify the proposed approach for determining the critical temperature of buckling, we used a finite element method implemented by the ANSYS software package[6,7,8,12,15]. A spatial panel of the given sizes was simulated and a static calculation of the temperature load was performed. Then, using the results of the static calculation and the built-in Eigenvalue Buckling module [4] in a linear setting, used to determine the level of loads at which the structure loses stability or to determine the safety factor for a given level of loading. Obtained by the different methods, the calculation results of the critical temperature of buckling are presented in Table 1. The result of numerical calculation of the buckling shape by the finite element method (FEM) is given in Fig.1.

Table. 1.

The calculation results of critical temperature of buckling

Geometrical sizes of the shell under consideration	Coefficients of the expansion members		T_{kp}, calculated by FEM, °C	T_{kp}, calculated by the Bubnov-Gallerkin method, °C
	m	n		
R=3000 мм h=2 мм L=900 мм S= 1500 мм	5	3	31,7	31,6
R=2000 мм h=1,5 мм L=900 мм S= 900 мм	9	1	37,3	37,5
R=1500 мм h=1 мм L=600 мм S= 600 мм	7	2	33,22	32,88

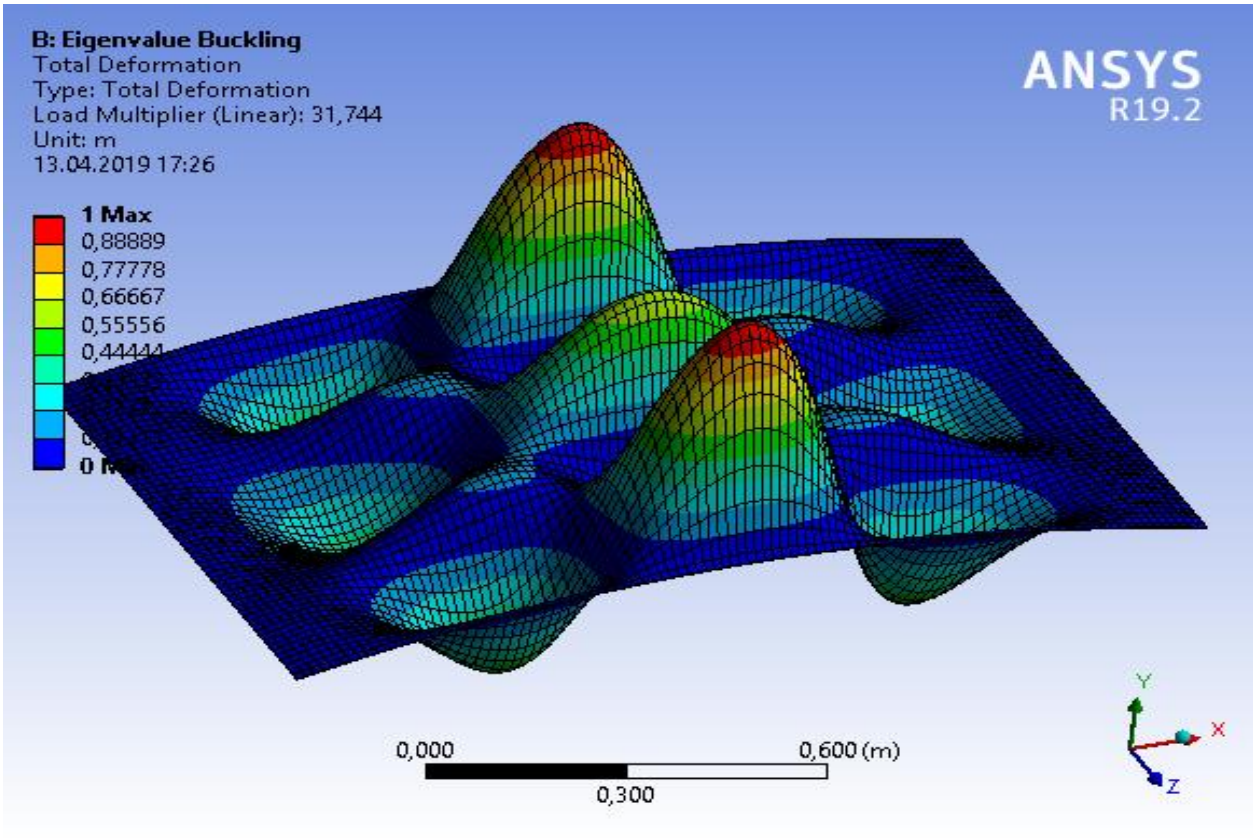

Fig.1 The buckling shape of shallow cylindrical shell

Conclusions and discussion

The calculations performed by different methods have demonstrated satisfactory agreement of the results obtained by the proposed approach with the calculation method. The maximal difference in the results does not exceed 1%. Thus, the proposed approach provides reliable results. It should be noted that to solve the buckling problems and obtain more in-depth results, a nonlinear analysis of a structure should be performed [5-6,11]. In this regard, it is additionally recommended to carry out the experimental studies of determining the true values of critical temperatures of buckling.

It should be taken into account that the proposed approach allows, without the use of expensive software packages, structural evaluation of critical temperatures and safety factors. The expression (5) will be of interest to designers of structures operating under various temperature conditions. If these parameters exceed some values, a developer can make the necessary design changes to correct the geometric dimensions or apply a passive thermoregulation system, for example, the use of coatings with a reduced coefficient of solar radiation absorption.

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