The 2017 World Congress on
Advances in Structural Engineering and Mechanics (ASEM17)
28 August - 1 September, 2017, Ilsan(Seoul), Korea

Stability of the metal cylindrical grid shell structures

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ABSTRACT

A technique for the stability analysis of metal cylindrical grid shell structures is developed. A mathematical model is constructed and dangerous sections of deformation of structures are revealed. Exact relationships of power characteristics and shape-forming parameters are obtained. The critical load is determined taking into account the half-wave form of the loss of stability and stiffness of multi-element grids. The results of numerical studies are presented. The difference in local and total loss of stability is shown. The limits of applicability of geometric parameters are found. An increased vulnerability of shells with a rhombic mesh is shown. The model is tested and the correctness of the proposed calculation procedure is confirmed.

1. INTRODUCTION

Studies of cylindrical reticulated shells by Yongjun He *et al.* (2012) on double-layer cross systems with reinforcing elements are known. The publication Yongjun He *et al.* (2015) carried out analysis of the stability of similar structures. However, the greatest attention is paid to single-layered surfaces of zero Gaussian curvature. As evidenced by the results of recent studies (Raghavan Ramalingam and S. Arul Jayachandran, 2015), dangerous variation of the geometry of individual sections from actual loads is possible. Based on the collected data and the design experience of Huihuan Ma *et al.* (2015), experimental and numerical studies of the shells were carried out. Obviously, the grid scheme, the method of applying external influences, and the boundary conditions have a significant effect on the operation of structures, and the need to follow economic principles also complicates the problem. The developed calculation methods are based on the use of iterative procedures and the results of experimental tests of continuous shells. The solutions obtained are applied to grid designs of arbitrary geometry and have a general approach to determining the value of the critical load. The conducted studies showed a large set of unaccounted factors and significant

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reserves of load-bearing capacity. However, cylindrical grid shell structures, in comparison with other curvilinear multi-element structures, are subject to substantial curvature of surfaces, have different schemes of geometry variation and the smallest strength parameters of stability. Therefore, in the proposed article, the goal is to develop a mathematical model for determining the critical load and to investigate the stability of the corresponding reticulated surfaces.

2. MATHEMATIC MODELING

The theory of thin continuous cylindrical shells is used. The corresponding notation for geometric and force parameters is introduced. The differential equation of stability has the form

$$D\nabla^8 w + \frac{Eh}{R^2}\frac{\partial^4 w}{\partial x^4} + qR\nabla^4\left(\frac{\partial^2 w}{\partial y^2}\right) = 0 \tag{1}$$

The reticulated shell structure is formed by longitudinal, transverse and diagonal rods (Fig. 1).

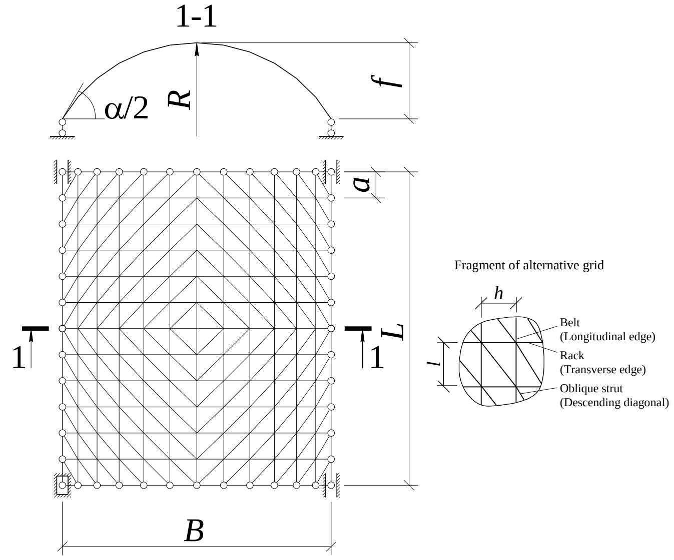

Fig. 1 Scheme of a reticulated cylindrical shell structure

Equivalent rigidity relations are represented in the form

$$D \sim \frac{EJs}{a};\quad Eh \sim \frac{EAs}{a} \tag{2}$$

Taking into account the hinged support of the grid along the contour and the shape at which the loss of stability is possible, it is found

$$q_{cr} = \frac{EAs}{aR}\left[\frac{J}{A}\left(\frac{\pi\alpha R}{nL^2}+\frac{n\pi}{\alpha R}\right)^2+\left(\frac{(\alpha R)^2}{R^2n^2\pi^2}\right)/\left(1+\frac{n^2L^2}{(\alpha R)^2}\right)^2\right] \tag{3}$$

Numerical studies of grid shell structures were carried out using various geometric parameters.

3. FINITE ELEMENT ANALYSIS

The dimensions of the test shell structure are B=36 m; f=9 m; R=22.5 m; a=3.01 m. The material of a structure is steel S235. The rods are seamless hot-rolled pipes $D\times t$=168×5.5 mm и 140×4.5 mm. As a result of the calculations, a negative influence of the increase in the length L on the quantity q_{cr} and the number of half-waves of the n shape of structural stability loss are obtained. The change in the ratio L/a along the generator is in the range from 12 to 48. We have determined the weak sensitivity of the shell to the exclusion of individual rods from work.

The value of the critical load is found depending on the different stiffness characteristics of the tubular rods with a possible cross-sectional area $A=16.7\times10^{-4}$ m^2; 18.8×10^{-4} m^2; 21.0×10^{-4} m^2; 23.2×10^{-4} m^2; 26.5×10^{-4} m^2. The increase in the size L along the generatrix is accomplished by adding the number of cells in the range from 6 to 42. The increase of the span B is created taking into account the constant radius of curvature R=22.5 m. By means of graphical construction, the range of admissible values of parameters and possible design of the structure is revealed. The strong sensitivity of the shell with a rhombic grid is determined.

4. EXPERIMENTS

The data obtained are confirmed by the results of experimental studies. For this purpose, a model with dimensions L=2.4 m; B=1.8 m; f=0.42 m; R=1.1 m; l=0.3 m; h=0.34 m is manufactured and tested. The rods are made of pipes $D\times t$=21×3 mm. Load is applied over the entire surface of the shell and on one side of it. The loads in hanging baskets, power equipment, instruments and stress gauges with a base of 10 mm are used.

The research methodology includes measurement of displacements and deformations, identification of areas with maximum internal force factors and deformation parameters, determination of the magnitude of the critical load and the form of loss of stability.

The test result revealed the greatest vulnerability of the system with the applied load on one slope. Moreover, in both schemes the number of half-waves n = 3 of the form of loss of stability turned out to be the same.

The maximum stresses in the rods and displacements of the nodes revealed by the test results decreased by 14-26%. The system, under the load, applied on the one edge, became less stable by 33% and received an excess of maximum displacement by 57%.

5. CONCLUSIONS

The use of the basics of thin shell theory for the curvilinear surfaces made it possible to construct a mathematical model and to develop a technique for calculating the stability of cylindrical reticulated shell structures.

The analysis of the state of structures is performed and dangerous sections of the geometry change are determined depending on the parameters of the form setting and the number of half-waves n in the direction of the arc of the circle.

The necessary components of the stiffness of multi-element grids are identified and it is possible to determine the critical load q_{cr} taking into account the exact ratios of the force and shape-forming characteristics.

A decrease in performance and a decrease in the number of half-waves of the n-form of structural stability loss are revealed with an increase in the number of cells along the generatrix.

The process of exclusion from the work of the maximally compressed rod has been investigated and the need to calculate the shell taking into account the lower critical load has been identified.

The limiting values of the $B \times L$ dimensions of the grid shell structure are determined and the area of possible design of the structure is shown.

A strong sensitivity of the shell with a rhombic grid is revealed.

Experimental studies of the model are carried out. The value of the critical load q_{cr} and the number of half-waves n of the stability loss form are obtained. Areas with the greatest internal force factors and deformation parameters are identified.

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