Experimental Studies of the Cylindrical Mesh Shell Model

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Abstract. Experimental studies of the effect of full and one-sided external load on a metal cylindrical mesh shell have been conducted. Regularities of stress and displacement distribution over the surface are recorded. The regions with the largest internal force factors and deformation parameters were identified. The values of the experimental critical load and the number of half wave of the form of stability loss are obtained. The risk of unilateral application of the load was established when the critical load was reduced and the maximum displacement exceeded.

1. Introduction
Experimental studies of metal cylindrical mesh shells formulate the problem of determining the actual nature of the stress-strain state and stability of the system under the action of a real load. Such studies can be carried out both on models [1] and in full size. However, model experiments require a lot of money and time [2-5]. It is necessary to take into account the large volume of full-scale construction and the complexity of testing large objects. In experimental practice, the interest in testing small models of such shells is not accidental. Based on the data obtained during the tests, acceptable results were established. Continuous improvement of the shells [6-16] leads to the need for new tests. There is a need to use rational design solutions. Usually, the study of shells is limited only to the elastic stage of operation [1, 16 and 17]. This leads to the determination of stresses in the elements and the movement of nodes with the study of the stability of the shells. [18-27]. The work includes the development of a method for physical modelling of cylindrical mesh shells, a sequence of experiments, and the main results.

2. Materials and methods of research
Experimental studies were conducted on a physical model of a cylindrical mesh shell in laboratory conditions at a temperature of + 20 ± 2°C and air humidity of 50%. Appropriate work has been done on the design and fabrication of the grid surface. The basic geometric parameters and material of the structure are shown in table 1.
Table 1. Geometric parameters and material characteristics.

| $L$ (m) | $B$ (m) | $f$ (m) | $R$ (m) | $l'$ (m) | $h^*$ (m) | $E$ (kN/m$^2$) | Steel |
|---------|---------|---------|---------|----------|-----------|---------------|-------|
| 2.4     | 1.8     | 0.42    | 1.1     | 0.30     | 0.34      | 2.06×10$^8$   | S235  |

*$l; h$ are cells dimensions

The system is assembled from longitudinal, transverse and diagonal rods. Elements are designed from hot-rolled seamless pipes (see table 2) and are interconnected by a sheet $4\times 10^{-3}$ m thick.

Table 2. Cross-section parameters of tubular rods.

| $D$ (m) | $t$ (m) | $A$ (m$^2$) | $J$ (m$^4$) | $J_t$ (m$^4$) |
|---------|---------|-------------|-------------|--------------|
| $21\times 10^{-3}$ | $3\times 10^{-3}$ | $1.7\times 10^{-4}$ | $7.1\times 10^{-9}$ | $19.1\times 10^{-9}$ |

The model is mounted on a specially manufactured support rod system, which consists of horizontal and vertical elements assembled together. The rigidity of the system is provided by pillars located along the perimeter in steps of 0.9-1.2 m. Before the start of the test, the instruments were calibrated and fixed on a three-dimensional frame structure. For its production, stainless steel angles with a shelf size of 0.05 and 0.063 m are used.

The nodal load application was implemented in stages at 2.37 kN in accordance with the schemes shown in figures 1(a) and 1(b).

![Figure 1](image1.png)

(a) Across the surface  
(b) On one slope

Figure 1. The schemes for the experimental load.

Loads $F_1$ and $F_2$ at the corner points and along the contour, respectively, are additionally applied by using a system of devices and clamps.

During the experiment, loads packed in hanging baskets, power units, equipment and strain gauges with a base of $10^{-3}$ m were used. The design of the model with necessary equipment is shown in figures 2(a) and 2(b).

![Figure 2](image2.png)

(a) General view  
(b) View from the edge

Figure 2. Experimental model for a shell test.
The research methodology included 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 stability loss.

3. Results and discussion
The tests performed and subsequent processing of the instrument readings allowed us to determine the influence of two load application schemes on the condition of the shell. The most dangerous scheme is one-way application of the load. The lower belt and the loaded slope of the shell are very vulnerable. The absolute maximum is here. The longitudinal support elements in the loaded slope all worked on tension. However, other elements located in the direction of the shell length were in a state of compression. From the results of model deformation, it follows that from the ends to the middle of the shell, there is a noticeable increase in the displacement of nodes. The most sensitive to load are the shell slopes. The absolute maximum is here in the vertical direction. In the lower belt, the nodes have also moved significantly horizontally.

The test result revealed the greatest vulnerability of the system with the load on one slope. Moreover, in both schemes the number of half-wave \( n = 3 \) of the loss of stability form turned out to be the same. The obtained indicators were compared with the results of the final element analysis. In table 3 shows the maximum numerical values of the main parameters.

| Scheme | \( N^- \) (kN) | \( N^+ \) (kN) | \( \delta_x \) (m) | \( \delta_z \) (m) | \( q_{cr} \) (kN/m²) |
|--------|--------------|--------------|-----------------|-----------------|-------------------|
| 1      | 14.12        | 16.71*       | 16.07           | 18.79*          | 0.069             |
|        | 0.087        | 0.132        | 0.165*          | 260.38          |
| 2      | 17.51        | 20.18*       | 19.76           | 22.55*          | 0.085             |
|        | 0.106*       | 0.207        | 0.243*          | 196.49          |

*results of the finite element analysis

The maximum stresses in the rods and deviations of the nodes revealed by the test results decreased by 14-26%. The system, under load, applied on the one edge, became less stable by 33% and received an excess of maximum displacement by 57%. Based on the experiment and the calculation, dependence graphs of the bearing capacity exhaustion and the maximum deflection are built (see figures 3(a) and 3(b)).

![Figure 3](image-url)  
Figure 3. Experimental and calculation results.

According to both schemes of applying external load, it can be seen that the curves with increasing vertical displacement tend to diverge. Their extrapolation when \( \Delta > 100\% \) corresponds to the loss of stability and the supercritical state of the structure.
4. Conclusions
The influence of two load application schemes on the state of the shell is determined. Regularities of distribution of stresses and displacements in the model over the surface with zones of their concentration are established. The most dangerous scheme is one-way application of the load. The maximum force has a stretched element. The largest displacement of the node occurred in the vertical direction.

Tests of the model of a cylindrical mesh shell on the action of a full and one-sided external load were carried out. Model studies allowed us to obtain the value of the experimental critical load $q_{cr}$ and the number of half wave $n$ of the loss stability shape. The increased risk of unilateral application of the load with a significant decrease in the value of $q_{cr}$ by 33% and exceeding the maximum displacement by 57% is established. The regularities of system behavior under the action of operational loads are determined. Areas with the greatest internal force factors and deformation parameters are identified. A comparison with the data of the finite element analysis showed a reduction in the ultimate forces in the rods and deviations of the nodes by 14-26%.

5. References
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